# LEARNING AND MEMORY

## A COMPREHENSIVE REFERENCE

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# FOREWORD

A comprehensive reference work on learning and memory could not be better timed than this. During the second half of the twentieth century, the study of learning and memory moved from a descriptive science largely based on the pioneering behavioral analyses of Pavlov, Thorndike, Watson, Skinner, Kamin, Rescorla, and Wagner to a new mechanistic science of mind that combines these brilliant behavioral studies with an analysis of the underlying neural mechanisms, first in a regional manner by Milner, Tulving, Mishkin, Squire, Schachter, and Morris, then on the cellular level, and finally on the molecular level.

The challenges that now face the field are outlined by the five great pioneers in the study of memory – the editor-in-chief Jack Byrne and the editors of these four extraordinary volumes: *Learning Theory and Behavior*, edited by Randolf Menzel; *Cognitive Psychology of Memory*, edited by Henry Roediger; *Memory Systems*, edited by Howard Eichenbaum; and *Molecular Mechanisms of Memory*, edited by David Sweatt. The challenge faced by the contributors to these volumes was to combine the molecular mechanisms with the other three levels in order to provide a coherent, systematically and intellectually satisfying understanding of learning and memory. This is central to the new science of mind. Since memory is the glue that holds our mental life together, the topics covered by these four volumes are central to and paradigmatic for all aspects of the neurobiology of mental life, which has as its goal the understanding of all mental processes in neurobiological terms. Indeed, it is the plasticity of the brain that is the key to understanding the continuity of all mental function. The goal for each of these four volumes was to bridge the subdisciplines concerned with the various forms of memory into a coherent science. The chapters of each of these volumes succeed admirably in doing just that. As a result, this rich and rewarding reference work will serve as a superb framework for the decades ahead, a reference that will provide both the student and the working scientist with the intellectual background necessary to understand and function effectively in the study of learning and memory.

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# PREFACE

*Learning and Memory: A Comprehensive Reference* is the most authoritative set of volumes ever produced on learning and memory and represents the state of the science in the early 21st century. The study of learning (the process of acquiring new information) and memory (retention of that information for future use) has intrigued philosophers and writers for centuries because our memories and plans for the future consolidate who we are, and disruption of these processes dramatically interferes with our daily lives. The fascination with learning and memory is not limited to the humanities, but has been the subject of intense scientific research. Psychologists are concerned with elucidating the features of learning and memory processes and systems, neurobiologists seek to determine the neuronal mechanisms of learning and memory, and neurologists and psychiatrists focus on research and treatment of failures or disruptions in learning and memory.

The study of learning and memory represents a scientific field that has matured at all levels – from the discovery of the protein chemistry and molecular biology of the cellular events underlying learning and memory, through the delineations of the properties and functions of neuronal networks, to formulating and testing the psychological and behavioral neuroscientific theories of learning and memory. In addition, many basic research findings have applied implications on such diverse fronts as education, legal issues hinging on eyewitness testimony, learning disorders in children, memory disorders following brain damage, and declines in memory in older adults.

The volumes in this *Comprehensive Reference* are the result of a meeting in London in July of 2005 where the editors planned the massive work of consolidating all facets of the study of learning and memory. We collected nearly all the topics (albeit from many different disciplines and directions) that we considered constituted scientific approaches to learning and memory and proceeded to parcel the topics into four volumes, resulting in *Learning Theory and Behavior* edited by Randolf Menzel; *Cognitive Psychology of Memory* edited by Henry Roediger III; *Memory Systems* edited by Howard Eichenbaum; and *Molecular Mechanisms of Memory* edited by David Sweatt. This was a formidable task, not only because of the richness and diversity of the subject matter, but also because we needed to logically place topics in the appropriate volume. Although some of the decisions may seem arbitrary, and indeed there is overlap both within and between volumes, each editor ended up with a set of coherent topics that they could organize and introduce in a logical manner.

With approximately 40 chapters per volume, it is no surprise that the editors cover an unusually wide range of intellectual territory or that there is a difference in interpretation by some authors. The organization is a significant editorial challenge and investment in and of itself. However, it is the editor's selection of authors, and the ensuing scholarship on learning and memory from different perspectives, that make this series unique. Authors were identified and invited based on their expertise on a particular topic, and their contributions represent a marvelous compendium of research in learning and memory. The chapters in this series not only represent scientific strength and breadth, but also range from learning at the synaptic level to a systems level approach, and include studies of remarkable learning capabilities in a variety of invertebrates and vertebrates, including human beings.

The first volume in the series, *Learning Theory and Behavior* edited by Randolf Menzel, consists of 38 chapters and sets the tone for the interdisciplinary and comparative approach to the study of learning and memory. He introduces the volume by emphasizing both the value and the limitation of the comparative approach in natural and laboratory settings, stressing that we need information from the behaving animal as well as the neuronal structures in order to understand the processes involved in information storage and retrieval. Several chapters review progress from using animal models, including worms, molluscs, insects, rodents, birds, and nonhuman and human primates. In addition, concepts such as planning, decision-making, self-awareness and episodic-like memory, usually reserved for human beings, are discussed at several taxonomic levels. The final chapters take an engineering perspective and describe synthetic approaches, including modeling neuronal function and developing a concise theory of the brain.

The second volume, *Cognitive Psychology of Learning* edited by H. Roediger, is comprised of 48 chapters on various aspects of cognitive ability and the underlying neuroscience. The basics of attention, working memory, forgetting, false memories, remembering vs. knowing, the process of recognition, and episodic memory are covered. In addition, topics that are often not included in "memory" volumes deservedly receive attention here, e.g., learning of concepts and categories, learning of perceptual and motor skills, language learning, and implicit learning. This volume also covers memory processes throughout the human lifespan and includes chapters on individual differences in memory ability, both subnormal (learning disabilities) and supranormal (performance of mnemonists and experts in particular domains). Finally, chapters on applied aspects of memory research, dealing with such topics as eyewitness identification in the legal system and applications of research to educational issues, are included.

Volume 3, edited by H. Eichenbaum, consists of 29 chapters which represent a "progress report" on what we know about memory systems and their relationship to different parts of the brain. *Memory Systems* returns to a comparative approach of learning and memory. This volume introduces the concepts of multiple memory systems, and many chapters discuss in extensive detail the different features of declarative memory and their underlying brain structures. Procedural learning in humans and other animals is addressed, and a short section details the involvement of hormones and emotions on memory retention or loss. Finally, changes in memory systems associated with aging, disease processes, and drug use are addressed.

The final 42 chapters in Volume 4, *Molecular and Cellular Mechanisms of Memory* edited by J.D. Sweatt, represent a review of the state of the science of what we know at the systems, cell, and molecular levels on learning and memory formation, as well as providing a look at the emerging and future areas of investigation. Once again, this volume covers an impressive amount of information derived from studies at many taxonomic levels, from molecular associative learning mechanisms, through an array of studies on synaptic plasticity, to the cell level of fear conditioning.

The centrality of learning and memory to our daily lives has led to intense analysis by psychologists and neurobiologists for the past century, and it will undoubtedly remain at the forefront of research throughout this new century as well. It is our intention that this set of volumes will contribute significantly to the consolidation of this field, and it is meant as a resource for scientists and students interested in all facets of learning and memory. No other reference work covers so wide a territory and in so much depth.

*Learning and Memory: A Comprehensive Reference* would not have been possible without the tremendous work of the Editorial Board, who identified the topics and their authors, and reviewed each contribution. Special thanks also go to Johannes Menzel, Senior Acquisitions Editor at Elsevier, for supporting the project and Andrew Lowe and Laura Jackson, Production Project Managers, and Joanna De Souza, Developmental Editor, for ensuring that the production schedule was maintained.

John H. Byrne

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Figure 10 of Learning to Time Intervals

# 2.01 Introduction and Overview

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## 2.01.1 The Cognitive Psychology of Memory: Introduction

The main problem in the scientific study of memory is that it proceeds on many different fronts. Neurochemical and neurobiological approaches propel some researchers; systems neuroscientists examine changes in larger pathways in the nervous system; animal behaviorists examine learning and memory as reflected in behavior of (mostly) infrahuman animals, such as birds finding caches of seed; cognitive psychologists study human memory through behavioral means using measures such as recall and recognition; computer scientists endorse computational approaches to memory that sometimes pay little attention to behavioral or neuroscience constraints; and, of course, the study of memory has been the topic of discourse by philosophers for over 2000 years. This four-volume series covers a huge selection of topics that are central to the scientific study of memory. In a different edited volume, Roediger et al. (2007) considered 16 critical concepts in the science of memory from the various viewpoints described above.

## 2.01.2 Cognitive Approaches to Memory

Practitioners of what is today called cognitive psychology have a long tradition of the experimental study of various aspects of memory. Experimental psychology is often dated from the founding of Wilhelm Wundt's laboratory in Leipzig in 1879. Coincidentally, that same year marks the year that Hermann Ebbinghaus (1850–1909) began his painstaking research that led to his great book, *Über das Gedächtnis (On Memory)* in 1885 (Ebbinghaus, 1885). Ebbinghaus conducted meticulous experiments that asked many fundamental questions about learning and memory, and virtually all his results have stood the test of time in that they have been widely replicated. His work dates the start of the cognitive/behavioral study of learning and memory in humans, although of course centuries of speculation and theorizing (particularly by the British empiricist philosophers) preceded and informed his first experimental efforts. Bower (2000) provides a brief historical overview of this approach to studying learning and memory.

Cognitive psychologists approach the problem of memory through careful experimentation to examine theories that vary in their levels of specification. Some theories (say, transfer-appropriate processing) are broad and seek to capture a wide range of performance across many situations, whereas other approaches (such as mathematical models of performance in specific tasks) are more formal and often attempt to capture memory performance only in tightly structured paradigms.

Traditionally, up until perhaps 30 years ago, cognitive psychologists paid little attention to neuroscience discoveries, and likewise, neuroscientists paid little attention to the experimental work of the cognitive psychologists. Although this division of labor is honored to some degree in the separate volumes of this work, the interests of scientists are clearly broader today. Unlike the case 30 years ago, cognitive psychologists today follow advances in neuroscience with great interest, and many of the concepts and tasks used by neuroscientists were originally developed by psychologists (either those studying animal learning and memory or those applying cognitive methods to these topics in humans). Although this volume is largely devoted to the cognitive/behavioral study of memory, many chapters lean heavily on neuroscience findings. The authors were given leeway to cover their particular topic from the vantage they deemed most appropriate, bringing in the types of evidence they considered most relevant. Some chapters rely heavily on neuroscience evidence, whereas others refer to purely behavioral experimentation. I see this as perfectly appropriate for the various topics covered in this volume.

## 2.01.3 Organization of the Volume

One time-honored procedure in the study of cognitive processes is sorting (e.g., Mandler, 1967). An experimenter can give a subject a set of concepts and ask him or her to sort them into groups. The hope is to discover something about how the subject's mind organizes experiences into concepts or categories. The titles of chapters for this volume were originally listed alphabetically, but then the editors of each volume were asked to organize them in some meaningful way, which corresponds reasonably well to a sorting task. I took several trials to reach criterion on this task and can still quibble with myself on various decisions. Luckily, the editors were not asked to create sections of the volume and to label our categories. Here I provide some rationale for the ordering of the chapters and, at the same time, outline the contents of the volume.

The volume begins with a chapter on attention and memory by Neil Mulligan (*See* Chapter 2.02). After all, events in the world that are not attended will not be encoded well and cannot be remembered later, so this seemed a logical starting point. Nelson Cowan's chapter on sensory memory (*See* Chapter 2.03) follows this one. Sensory memory (iconic storage, echoic storage, and similar processes in other modalities) lies at the borderline between perceiving and remembering. No one has ever proposed a good solution to the question of where perceiving ends and remembering begins, and ideas about sensory storage bridge this gap. Susan Gathercole's chapter on working memory comes next (*See* Chapter 2.04). The topic of how people hold information in mind while manipulating it in reasoning and solving problems represents a huge topic in cognitive psychology over the past 40 years. The next chapter is on serial learning by Alice Healy and William Bonk (*See* Chapter 2.05). Most research on serial learning uses paradigms requiring short-term recall (such as digit span and similar procedures), so placing it after the working memory chapter seems reasonable. However, the chapter also covers long-term processes in serial organization.

Robert Greene provides a chapter on the fundamental topic of repetition and spacing effects (*See* Chapter 2.06). Perhaps the first principle of learning and memory is that repeated experiences are (almost) always better remembered than single experiences; further, having two experiences distributed in time (up to some limit that differs for various tasks and retention intervals) leads to greater performance. Another fundamental principle, dating at least to George Miller's (1956) pioneering work on recoding in memory, is that events are not remembered as they are presented in the outside world (events do not somehow leap into the brain as veridical copies of experience), but, rather, events are coded (or recoded) as they are filtered through an individual's personal experiences (or apperceptive mass, to bring back a useful term from early in psychology). Events are remembered as they are coded and not as they necessarily 'are' in the environment. Reed Hunt's chapter on coding processes brings out this important point and shows how recoding can improve retention in some cases but in other cases can lead to errors (*See* Chapter 2.07). Mental imagery is one type of code that has received great attention in the literature, and Cesare Cornoldi, Rossana DeBeni, and Irene Mammarella review this literature in the next chapter (*See* Chapter 2.08).

An event that differs dramatically from many other events that are themselves similar is usually well remembered, which constitutes a distinctiveness effect. For example, a picture of a horse embedded in the middle of a 99-word list of other concrete nouns is much better remembered than if the word 'horse' is presented in a uniform list of 100 words (with 'horse' embedded in the analogous position in the list). This outcome occurs even if the mode of recall is verbal (i.e., people must recall the word 'horse' both when it is presented as a picture and as a word). Distinctiveness effects are ubiquitous in memory research, and Stephen Schmidt provides a review of what is known about this topic in his chapter 'A Theoretical and Empirical Review of the Concept of Distinctiveness in Memory Research' (*See* Chapter 2.09). The next chapter, 'Mnemonic Devices: Underlying Processes and Practical Applications,' by James Worthen and Reed Hunt, brings together the chapters on recoding, imagery, and distinctiveness by reviewing techniques for memory improvement that have been developed over the years (*See* Chapter 2.10). Some of these techniques date back to the ancient Greeks, but modern research has helped to uncover the reasons for their effectiveness. Many of these techniques depend on imagery, and some (such as the method of loci) rely on humans' ability to remember routes and spatial layouts well, especially ones experienced repeatedly. Timothy McNamara, Julia Sluzenski, and Bjorn Rump review the interesting topic of human spatial memory and navigation (*See* Chapter 2.11).

The next chapters in the volume have to do with memory losses and errors. Forgetting refers to the loss of information over time, and James Nairne and Josefa Pandeirada review the topic in their chapter by that name (*See* Chapter 2.12). A complementary topic is on inhibitory processes, a chapter by Karl-Heinz Bauml (*See* Chapter 2.13). Inhibitory processes are concerned with another set of phenomena that have to do with forgetting. The basic idea is that forgetting may result from an active process of memories being inhibited and therefore forgotten, at least temporarily. Forgetting is often considered an error of omission – information does not come to mind when we try to retrieve it – but errors of commission are of great interest, too. False memories arise when we retrieve information differently from the way it was experienced or, in the most dramatic cases, when we retrieve confident memories of events that never happened at all. Elizabeth Marsh, Andrea Eslick, and Lisa Fazio review this topic in their chapter titled 'False Memories' (*See* Chapter 2.14). Eric Eich, Elke Geraerts, Jonathan Schooler, and Joseph Forgas provide a chapter on mood and emotion in memory, titled 'Memory in and About Affect' (*See* Chapter 2.15). When people are in different moods when they experience events and then try to retrieve them later, they often remember more poorly than if the moods are the same between encoding and retrieval (the phenomenon of mood-congruent memory). However, when people experience greater emotional states during encoding (e.g., strong fear), they often remember events well.

The next few chapters have to do with retrieval of information from memory, as well as associated states of consciousness and processes during this process. Suparna Rajaram and Sarah Barber provide an overview of retrieval processes in memory (*See* Chapter 2.16). John Gardiner writes on the distinction between remembering and knowing, which are responses representing two states of conscious awareness during retrieval (*See* Chapter 2.17). Asher Koriat, Morris Goldsmith, and Vered Halamish discuss control processes in voluntary remembering, dealing with issues such as the criterion people use when deciding that recovered information should be reported as a memory and the factors affecting memory reports (*See* Chapter 2.18). Stephen Lindsay writes on the related topic of source monitoring, or the issue of how people recollect the source of information they report as a memory – did I read the fact in the newspaper, did a friend tell me, or was it learned from television (*See* Chapter 2.19)? Janet Metcalfe and John Dunlosky write on the issue of metamemory, or what people know about their own memories and the strategic processes used in regulating encoding and retrieval of information (*See* Chapter 2.20). Alan S. Brown has provided two chapters on puzzling phenomena of memory retrieval, the experience of déjà vu (when a person has the strange sensation that an event or scene has been experienced previously), and the tip-of-the-tongue phenomenon (the annoying experience when a desired bit of information can almost, but not quite, be retrieved) (*See* Chapters 2.21, 2.22).

Colleen Parks and Andrew Yonelinas provide the chapter 'Theories of Recognition Memory' (*See* Chapter 2.23), with particular emphasis on whether a single-factor or two-factor theory best accounts for the data. William Hockley writes about the related topic of memory search in various types of memory tests, including short-term recognition (S. Sternberg's (1966) item recognition test), long-term recognition, free recall, and other tasks (*See* Chapter 2.24). Both the chapter on recognition and the chapter on memory search involve considerations of mathematical modeling, and the next chapter by Jeroen Raaijmakers explicitly considers mathematical models of human memory (*See* Chapter 2.25). His chapter is followed by a related one by Michael Kahana, Marc Howard, and Sean Polyn on associative retrieval processes in episodic memory (*See* Chapter 2.26). Karl Szpunar and Kathleen McDermott provide an overview on the concept of episodic memory as it has developed since Tulving's seminal chapter in 1972 (Tulving, 1972) (*See* Chapter 2.27). They discuss how neural processes involved in episodic memory may also subserve a person's envisioning the future as well as recollecting the past.

The next series of chapters involves memory of a different kind from episodic memory. David Balota and Jennifer Coane's chapter on semantic memory concerns representation of well-learned information such as words and their meanings (*See* Chapter 2.28). Brian Ross, Eric Taylor, Erica Middleton, and Timothy Nokes survey the related field of how humans learn concepts and categories in 'Concept and Category Learning in Humans' (*See* Chapter 2.29). Gideon Deák and Anna Holt describe research on the critical issue of language learning and report how theories have advanced over the years (*See*

Chapter 2.30). Peter Frensch and Hilde Haider discuss research on the venerable topic of transfer and expertise (*See* Chapter 2.31), a topic that really runs throughout the book in many ways.

Pierre Perruchet reviews the evidence concerning implicit learning, which uses transfer designs as a major tool for understanding (*See* Chapter 2.32). Dale Stevens, Gagan Wig, and Daniel Schacter then review recent evidence on the related topic of implicit memory and priming (*See* Chapter 2.33). Timothy Lee and Richard Schmidt provide an overview on the topic of motor learning and memory, which is related to implicit learning in some ways (*See* Chapter 2.34). Much recent work has shown that procedural and motor skills (as well as some other forms of learning) consolidate while people sleep. Jessica Payne, Jeffrey Ellenbogen, Matthew Walker, and Robert Stickgold review this exciting frontier in memory research in 'The Role of Sleep in Memory Consolidation' (*See* Chapter 2.35).

The next group of chapters is concerned with development of memory across the lifespan, as well as individual differences among people in memory ability. Carolyn Rovee-Collier and Kimberly Cuevas review evidence about infant memory (*See* Chapter 2.36), and then Peter Ornstein, Catherine Haden, and Priscilla SanSouci consider the development of skilled remembering in children (*See* Chapter 2.37). Elena Grigorenko discusses developmental disorders of learning (*See* Chapter 2.38), and Michelle Dawson, Laurent Mottron, and Morton Gernsbacher describe learning in autism (*See* Chapter 2.39). Michael Kane and Tina Miyake write about individual differences in episodic memory among adults (*See* Chapter 2.40), and Moshe Naveh-Benjamin and Susan Old discuss aging and memory (*See* Chapter 2.41). Finally, Anders Ericsson describes research on superior memory of mnemonists and experts in various domains (*See* Chapter 2.42).

The next few chapters of the book focus on more applied aspects of learning and memory research. Mark McDaniel and Aimee Callendar discuss work on cognition, memory, and education, focusing on applying principles from learning and memory research to educational practice (*See* Chapter 2.43). Jeffrey Neuschatz and Brian Cutler discuss the important issue of eyewitness identification (*See* Chapter 2.44). Since the advent of DNA evidence, over 200 people convicted of crimes – often on the basis of eyewitness evidence - have been released from prison, exonerated by DNA evidence. This state of affairs has caused a searching examination of the typical methods used by police to conduct eyewitness identifications. Gilles Einstein, Mark McDaniel, Richard Marsh, and Robert West discuss another popular topic in recent research – how people remember to do things in the future, such as taking an antibiotic pill four times a day when fighting an infection. Their chapter, 'Prospective Memory: Processes, Lifespan Changes, and Neuroscience,' discusses this interesting line of research (*See* Chapter 2.45).

The last three chapters of the volume examine memory from a broader perspective. Most chapters previously described are based on laboratory tasks concerned with learning and memory. Martin Conway and Helen Williams write on the nature of autobiographical memory, which is concerned with how people recollect the events of their lives (*See* Chapter 2.46). Michael Ross, Craig Blatz, and Emily Schryer discuss social memory processes, which includes the issue of how people influence one another as they remember (as well as other topics) (*See* Chapter 2.47). Finally, James Wertsch discusses the emerging topic of collective memory (*See* Chapter 2.48), which is a representation of the past that is shared by members of a group. The group might be people in a nation recollecting an important historical event, such as how people in the United States remember the Revolutionary War. Different groups may see the past in different ways, as Wertsch brings out in his chapter. The empirical study of collective memory is an emerging topic but one that is sure to be more important in the future.

## 2.01.4 Conclusion

The 47 substantive chapters in this volume represent a marvelous, state-of-the art digest by leading scholars as they summarize what is known about many of the critical topics in the cognitive psychology of learning and memory. The entries range from topics that have a long history (e.g., transfer) to those that have emerged only recently (prospective memory, collective memory). Editing the volume has caused me to learn much, and I believe every reader of this volume will share this experience.

## References

Bower GH (2000) A brief history of memory research. In: Tulving E and Craik FIM (eds.) *Oxford Handbook of Human Memory*, pp. 3–32. New York: Oxford University Press.

Ebbinghaus H (1885) *Über das Gedächtnis*. Leipzig: Dunker & Humblot.

Mandler G (1967) Organization and memory. In: Spence K and Spence JT (eds.) *The Psychology of Learning and Motivation* , Vol. 1, pp. 327–372. New York: Academic Press.
Miller GA (1956) The magical number 7, plus or minus 2: Some limits on our capacity for processing information. *Psychol. Rev.* 63: 81–97.
Roediger HL, Dudai Y, and Fitzpatrick SM (2007) *Science of Memory: Concepts*. Oxford: Oxford University Press.
Sternberg S (1966) High speed scanning in human memory. *Science* 152: 652–654.
Tulving E (1972) Episodic and semantic memory. In: Tulving E and Donaldson W (eds.) *Organization of Memory*, pp. 381–403. New York: Academic Press.

# 2.02 Attention and Memory

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> Very great is the dependence of retention and reproduction upon the intensity of the *attention* and *interest* which were attached to the mental states the first time they were present. [italics in original] (Ebbinghaus, 1885: 3)

> Whatever future conclusions we may reach as to this, we cannot deny that *an object once attended to will remain in the memory,* whilst one inattentively allowed to pass will leave no traces behind. [italics in original] (James, 1890: 427)

## 2.02.1 Introduction

This chapter provides a brief overview of the relationship between attention and memory. The above quotations, although specifically written about the relationship between attention and long-term memory, provide a traditional viewpoint articulating the intimate connection between these constructs. Indeed, as Norman (1969) notes, a researcher would have little difficulty finding similar speculations in the earliest surviving writings in philosophy of mind. Ancient practical manuals on memory and rhetoric begin with the fundamental assumption that successful memory starts with attention (Yates, 1966). Modern researchers in cognitive psychology are likewise interested in attention and memory, but typically for theoretical reasons rather than the practical demands of the rhetorician's 'art of memory.' We shall see that, despite disputes about the details, these quotations remain quite apt regarding many aspects of the relationship between attention and memory.

At the outset, it should be noted that there is a tremendous amount of research under the general heading of 'attention and memory,' enough to require a book-length review even in the early days of the 'cognitive revolution' (Norman, 1969), and even more so in later eras (Cowan, 1995). Consequently, this short review is necessarily selective and incomplete. My goal is simply to describe some of the most important trends and results and to point the interested reader in the direction of additional resources. To begin, we briefly discuss the varieties of memory and the varieties of attention before proceeding to discuss the relationship between the two.

### 2.02.1.1 Varieties of Memory

Psychologists have long found it useful to differentiate among forms or aspects of memory. The most basic distinction is based on duration, the difference between immediate, fleeting retention of recently presented material and longer-lasting, more permanent aspects of memory. This distinction was captured early on in James's distinction between primary and secondary memory and was similarly delineated in the modal model of Atkinson and Shiffrin (1968), with its distinction between the short-term and long-term stores. Contemporary psychology continues to distinguish between shorter-term and longer-term memory, as well as among different forms of long-term memory, based on neuropsychological, neuroscientific, and behavioral evidence (e.g., Schacter et al., 2000).

Working memory is the current term for short-term or primary memory, although this conception is more complicated than the unitary short-term store envisaged in the modal model. Working memory is the system responsible for the short-term storage and manipulation of mental representations and contains three primary components, the phonological loop, the visuospatial sketchpad, and the central executive (Baddeley, 1986). The phonological loop is the mechanism responsible for the storage and rehearsal of phonological/verbal information. In a similar way, the visuospatial sketchpad provides temporary maintenance of visual and spatial patterns. The central executive coordinates the operation of these two subsidiary components and mediates the manipulation and transformation of information in these subsystems. The central executive is often associated with limited-capacity attentional resources (Engle, 2002), as discussed later. Finally, a recent version of the working memory model (Baddeley, 2002) proposes an additional component, the episodic buffer, responsible for binding together information represented in different forms or codes (**Figure 1**).

As short-term memory has been fractionated into multiple components, recent theorizing also distinguishes among multiple forms of long-term memory. These distinctions are based on several dimensions, key among them differences in phenomenology and differences in informational (or representational) content. First, it is common to differentiate among varieties of long-term memory based on phenomenology at retrieval, that is, whether the retrieval produces conscious recollection or not. This is critical to the distinction between explicit memory, which refers to conscious, intentional recollection of the past, and implicit memory, which refers to unconscious or unintentional influences of the past. Numerous differences (or dissociations) between explicit and implicit memory lend credence to the importance of this distinction (e.g., *See* Chapter 2.33; Mulligan, 2003b). The distinction between recollection and familiarity made in dual-process models of memory similarly relies on differences in the phenomenology of retrieval (Yonelinas, 2002).

Distinctions based on informational content are important to the multiple systems view of long-term memory (e.g., Schacter et al., 2000), a view that overlaps with distinctions based on phenomenology. First, and most important for our present purposes, is episodic memory, long-term memory for personally experienced events. This form of memory records autobiographical experiences that occurred at a specific time in a specific place. As noted by Tulving (2002), this form of memory permits 'mental time travel,' allowing a person to reexperience an event from the first-person perspective. Episodic memory overlaps with the concept of explicit memory because it supports the conscious and intentional recollection of the past. Semantic memory refers to the organized body of general knowledge about the world. This form of memory includes concepts, categories, vocabulary, and so on. This form of memory is distinguished from episodic memory by its depersonalized nature. Retrieving information from semantic memory is tantamount to retrieving facts rather than reexperiencing prior episodes.

The perceptual representation system (PRS) is

> a collection of domain-specific modules that operate on perceptual information about the form and structure of words and objects. (Schacter et al., 2000: 635–636)

This system represents long-term knowledge of perceptual objects in the modality in which they are processed. Finally, procedural memory is the system that represents skilled behaviors, including perceptual and motor skills, as well as more abstract cognitive skills. This system is marked by slow, incremental strengthening of representations through repeated practice. Procedural memory encompasses the learning of motor skills, such as riding a bike or

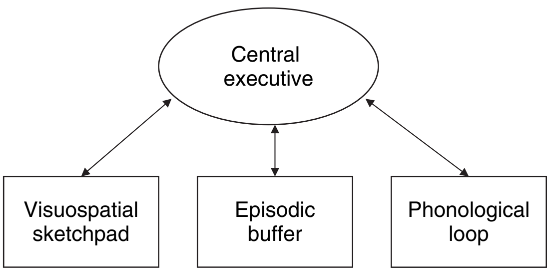


**Figure 1** The working memory model. Adapted from Baddeley AD (2002) Is working memory still working? *Eur. Psychol.* 7: 85–97, with permission.

swinging a golf club, as well as cognitive skills, such as learning to read.

Conscious recollection (explicit memory) is associated with the episodic system. Implicit memory is more various, forms of which appear to be mediated by each of the other nonepisodic systems. For example, perceptual priming (one manifestation of implicit memory) is attributed to the PRS, whereas conceptual priming is attributed to the operation of the semantic system. Finally, the expression of procedural skills is also associated with implicit memory.

### 2.02.1.2 Varieties of Attention

Just as memory is multifaceted, so too is attention. To begin, let us examine James' classic definition of attention:

> It is the taking possession by the mind, in clear and vivid form, of one out of what seems several simultaneously possible objects or trains of thought. Focalization, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others. (James, 1890: 403)

From such a description, researchers have typically teased out several aspects or dimensions of attention. First, attention is used for selection among the multitude of stimuli that impinge on our senses at any given moment. Perception would lack coherence if we attempted extensive analysis of every stimulus in the perceptual field. Second, attention implies a limited ability to process information. This is often characterized as a limited pool of attentional resources. Third, attention pertains to control in several ways: control of the flow of information, control of ongoing behavioral responses, and control of prepotent responses (e.g., inhibition).

The dominant distinction in recent research is between peripheral (or modality-specific) aspects of attention (such as visual attention) and central (or modality-independent) aspects of attention. For example, Johnston et al. (1995) propose a distinction between input and central attention, which distinguishes two limited-capacity mechanisms: one responsible for selective aspects of attention, and the other involved in higher-level mental functions (decision making, response selection, etc.). The distinction between selective and central attention corresponds quite closely to similar distinctions made in the literature on attention systems (Wickens, 1984; Duncan et al., 1997; Duncan, 1999), such as the distinction between perceptual and decisional attention (Ashby et al., 1998; Maddox, 2002), the distinction between perceptual and executive attention (Pashler, 1998; Engle, 2002), and the distinction raised in the neuroscience literature between the posterior and the anterior attention systems (Posner and Peterson, 1990; see also Freiwald and Kanwisher, 2004; Humphreys and Samson, 2004). Finally, the concept of central attention is often associated with the central executive component of Baddeley's (1986) model of working memory (e.g., Engle, 2002).

Studies of selective attention and central attention have typically used different experimental paradigms. In the typical experiment on selective attention, multiple stimuli are presented in the same modality, and the participant's attention is either directed at a critical stimulus or directed away from the critical stimulus by requiring the participant to respond to other (distracter) stimuli. Studies of central aspects of attention typically use divided-attention (or dual-task) paradigms. In these experiments, the participant is presented with two streams of stimuli in different modalities (e.g., visual and audition) and required to divide attention across the two sets. This is usually done by requiring the participant to respond to both streams of stimuli and by instructing the participant that both types of responses are important (i.e., encouraging the participant to divide attention equally over both tasks).

## 2.02.2 Attention, Memory, and the Beginnings of the 'Cognitive Revolution'

### 2.02.2.1 Cherry's Dichotic Listening Studies

Many of the landmark studies of the studies of the modern era of cognitive psychology focused on attention and memory. Specifically, studies of dichotic listening sought to analyze the role of selective attention in perception and memory. The initial study was that of Cherry (1953), who pioneered the experimental paradigm that would have such profound effect on later empirical and theoretical work. Cherry and the other early researchers were taken by the 'cocktail party problem,' which serves as a natural example of selective attention. At a cocktail party, there may be numerous conversations occurring all around the listener, any one of which could, in principle, be comprehended if attention were so directed.

A person in a conversation must attend to one speaker (and filter out all of the competing messages) to successfully take part in the conversation. How does this occur, and what is the fate of the unattended message(s)? To study this problem, Cherry developed an experimental analogue that would set the agenda for much of the early research on attention and memory. In this experimental technique, participants attended to one of two simultaneously presented messages. The messages were presented over different tracks of a stereo headset so that one message was presented to one ear, and a different message was presented to the other ear. The attended message was human speech, and the ignored message might consist of other human speech (in English or in another language), reversed speech, music, a steady tone, and so on. To ensure that subjects were attending to the correct message, the message was repeated by the subject as it was heard – a task called shadowing. The message that was not shadowed can be characterized as ignored or irrelevant rather than unattended. Although the goal of the dichotic listening task is to render the irrelevant message unattended, this may not always happen. It is possible that subjects might shift their attention on occasion to the nonshadowed message, undermining the goal of the experimental technique. This possibility makes a more neutral term (ignored or irrelevant) a better designation for the nonshadowed input.

Cherry found that subjects were successful in the shadowing task when the two messages differed in terms of their physical properties. The typical physical difference between the messages was spatial location, with one message presented to one ear and the competing message presented to the other. The messages could also be successfully segregated (and one successfully shadowed) when both messages were presented on the same track, provided the messages differed on another physical dimension, such as a male versus a female voice. However, if the two messages were physically similar (e.g., same location, or input ear, and same or similar voices), then the shadowing task became extremely difficult even if the messages differed in other ways, such as the topic or meaning of the messages. Cherry concluded that selection could only operate on the physical characteristics of the message and not on their content.

Most important for the present purposes was the memorial fate of the ignored message. Consistent with his conclusions about selection, Cherry (1953) found that only the physical properties of the ignored message were later remembered. After the shadowing task was over, subjects were asked what they remembered of the ignored message. Typically, subjects could remember whether it was human speech as opposed to a tone or music. Furthermore, they could recall whether it was a male or female voice. However, the subjects showed very little memory for the content of the unattended speech. That is, they showed little memory for words or phrases in the unattended message. Moray (1959) showed that, even when the same word was presented repeatedly – as many as 35 times – in the ignored ear, there was no memory for the stimulus. Furthermore, subjects were not entirely certain that the language was English. Reversed speech and speech in other languages were rarely recognized as non-English. Cherry's broad conclusion was that the unattended material is analyzed at the level of gross perceptual characteristics, but that selective attention is required for the analysis of and long-term memory of detailed aspects of the message such as the language spoken, the identity of individual words, and semantic content.

#### 2.02.2.2 The Filter Model and the Debate between Early and Late Selection Theories

From research on dichotic listening, Broadbent (1958) developed an early, highly influential information processing account of attention, perception, and memory (**Figure 2**). In this model, Broadbent depicted cognition as a series of discrete, serial information-processing stages. Processing begins with sensory systems, which can process large amounts of raw sensory information in parallel. Other research (e.g., split-span studies) indicated that sensory information may be preserved for a short time prior to selection. Thus, Broadbent argued that the initial sensory processing of the perceptual characteristics of inputs was deposited into a short-term memory buffer. This is the point at which attention operates in Broadbent's model, acting as a selective filter. The filter blocks out unwanted inputs based on selection criteria that reflect the goals of the cognitive system. For example, given that the subject's goal is to succeed at the shadowing task, selection is based on the physical location of the to-be-attended message. The selection criteria operate on one of the perceptual characteristics of inputs in the memory buffer. The attended material gains access to a limited-capacity perceptual system (the P system in **Figure 2**), which allows analysis for content, conscious awareness, and ultimately, encoding into long-term memory.

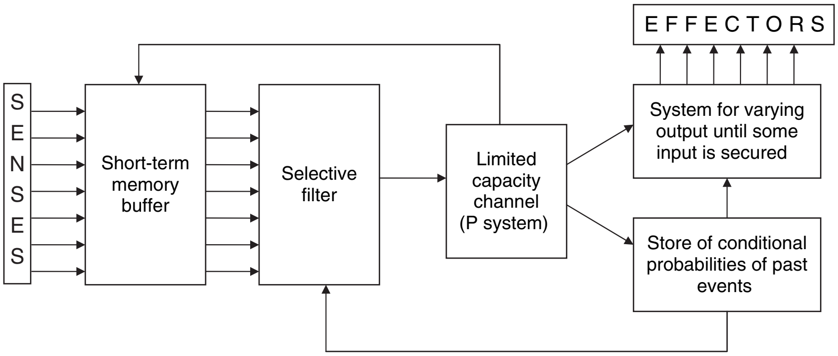


**Figure 2** The filter model. Adapted from Broadbent DE (1958) *Perception and Communication.* London: Pergamon Press, with permission.

It should be noted that Broadbent's model has many similarities to the Atkinson and Shiffrin (1968) modal model. The memory buffer in Broadbent's model corresponds to the sensory register of Atkinson and Shiffrin, in that both store raw sensory information prior to selective attention and refined perceptual analysis. The limited-capacity perceptual system of Broadbent is analogous to the short-term store of Atkinson and Shiffrin in terms of its limited capacity, its equation with the contents of awareness, and its role as a conduit to long-term storage.

Broadbent's model proposed that the selective filter operates on the basis of physical characteristics of the message and prior to the analysis of meaning. Consequently, this model is referred to as an early-selection model of attention. Subsequent research on the filter theory raised questions about early selection and gave rise to important competitor models. For example, Moray (1959) found that participants often noticed their own name when it was presented in the ignored channel. According to the filter model, detailed content such as the identity of a word or name should be unavailable from an unattended message. A converging result came from Treisman's (1960) study, in which one story was presented to the attended ear (and shadowed by the subject) and a second story was presented to the ignored ear. Partway through the study, the first story switched tracks and replaced the story in the ignored ear (the first story itself being replaced in the attended track with a new, third, story). According to the filter theory, if the subject is not attending to the irrelevant ear, then they should not process any of its content, and thus should have no awareness that the first story continued in the irrelevant channel. However, subjects typically continued to shadow the first story even after it switched ears. Neither of these results comports with Broadbent's original filter model.

Treisman (1964) handled these new findings by modifying Broadbent's theory. Treisman argued that selective attention does not operate as an all-or-none filter but, rather, operates like a gain control, attenuating unattended inputs. Such attenuated stimuli still might be recognized (i.e., their content fully analyzed) if the stimulus is very important (such as one's own name) or has been primed by attended semantic context. This attenuation view preserves the early placement of the selective filter (now an attenuator) as operating prior to semantic analysis and the processes required for encoding into long-term memory.

An alternate approach was adopted by late selection models (e.g., Deutsch and Deutsch, 1963; Norman, 1968). These models proposed that stimuli routinely undergo substantial analysis (up to identification processing), whether attended or not. The selective mechanism in these models operates after perceptual and content analysis but before response selection. Under this view, semantic analysis helps determine which stimulus is most relevant for current goals and should guide behavioral response.

A number of subsequent results were taken as supportive of late selection. For example, Lackner and Garret (1972) found that the interpretation of ambiguous sentences in the attended ear was biased by words presented in the ignored channel. The results of Corteen and associates (Corteen and Wood, 1972; Corteen and Dunn, 1974) were similarly interpreted as supporting late selection and memory access without attention. Participants in these studies initially underwent a learning phase in which a set of words was paired with electric shock. In a subsequent phase of the experiment, participants showed a heightened galvanic skin response (GSR) to the shock-paired words even when these words were presented to the ignored channel in a dichotic listening task.

Results such as these imply semantic analysis of unattended information (and late selection) but have been controversial because of the possibility of covert shifts of attention. It is possible in dichotic listening tasks (and in other selective attention tasks) that a subject's attention might wander to the nominally unattended ear. The critical question is whether results such as the above represent semantic analysis of unattended information or momentary shifts of attention to the ignored ear. As framed by Lachter et al. (2004), the issue is whether there is leakage (penetration of the selective filter by semantic content) or slippage (covert, perhaps unintentional, shifts of attention). In a review of the literature, Holender (1986) concluded that results that appear to support late selection in auditory selective attention are actually the result of such attentional slippage. A more recent review comes to the same conclusion for studies of both auditory and visual selective attention (Lachter et al., 2004). Furthermore, Lachter et al. (2004: 884–885) argue that the potential for slippage was underestimated in early research because estimates of the time necessary for attentional shifts were quite high (estimated to be 500 ms or longer in Broadbent (1958)). More modern estimates are as low as 150 ms for voluntary (endogenous) shifts of attention and 50 ms for involuntary (exogenous) shifts. If attention can be so rapidly shifted from one stimulus (or channel) to another, it raises the possibility that rapid shifts of attention might go unnoticed by the experimenter.

This issue has been raised regarding a number of studies. Following up on the results of Corteen and Dunn (1974), Dawson and Schell (1982) presented shock-associated words in the ignored channel of a dichotic listening task. Trials were separated based on evidence for attentional shifts to the ignored channel (based on on-line performance such as shadowing errors). The heightened GSR effect was much greater on trials exhibiting evidence of attention shifts than on trials exhibiting no such evidence. In a similar vein, Wood et al. (1997) varied the difficulty of the primary shadowing task (by increasing the rate of speech to be shadowed) under the assumption that, as the shadowing task becomes more demanding, covert attentional shifts to the ignored channel would be less likely. Evidence for semantic processing and long-term memory of the ignored channel was only found for easier shadowing tasks; no such evidence was found for the more demanding shadowing task, consistent with the idea that covert shifts of attention may give the appearance of semantic processing and long-term memory for unattended materials (for thorough review of these issues, see Holender, 1986; Lachter et al., 2004).

Finally, working memory resources, to be discussed in more detail next, may play a critical role in selective attention. For example, Conway et al. (2001) investigated the cocktail-party effect of Moray (1959), with participants of high and low working memory capacity. Prior research indicates that low working memory capacity is associated with distractibility. Conway et al. (2001) reasoned that more distractible subjects are more likely to allow their attention to shift to the irrelevant channel. This study found that the low-capacity subjects were much more likely to notice their name in the irrelevant channel. This result is consistent with the previous research suggesting that attention shifts may be responsible for the appearance of semantic processing of the ignored channel. In addition, this result indicates a close connection between working memory and selective attention. Similarly, deFockert et al. (2001) found that increasing a working memory load made subjects more susceptible to distraction in a visual selective-attention task. Several researchers have now suggested that selective attention processes are controlled by working memory resources (e.g., Engle, 2002; Lavie et al., 2004). That is, working memory capacity may dictate the extent to which we can successfully focus on one input in the face of distraction (as in dichotic listening). From a historical perspective, this is an interesting inversion. Psychology has traditionally described attention as controlling access to memory structures, but this view implies that a memory structure (working memory) controls the function of an attentional process (selective attention).

## 2.02.3 Working Memory and Attention

The concept of immediate or short-term memory has long been defined in terms associated with attention. For example, in the modal model of Atkinson and Shiffrin (1968), the presence of information in the short-term store rendered it available to consciousness and allowed the information to guide and control ongoing behavior. Attention is likewise associated with conscious awareness and control of behavior. The short-term store is defined as having a sharply limited capacity, as is attention when discussed in terms of processing resources. The same points could be made about the limited-capacity perceptual system in Broadbent's filter model. Of course, short-term memory is currently conceptualized in terms of the working-memory model (Baddeley, 1986), which contains specialized subsystems. However, the subsystems are similarly characterized as limited-capacity processing resources, although in the case of the phonological loop and visuospatial sketchpad, the resources are applied for specialized purposes.

In the modal model, the digit span task was the standard measure of the capacity of short-term memory, which along with numerous other assessments of capacity, yielded the famous estimate of $7 \pm 2$ (Miller, 1956). In the contemporary working memory model, digit span (along with other simple span tasks) is interpreted as a measure of the phonological loop. Analogous measures assess the capacity for storing visual and spatial information in the visuospatial sketchpad. For example, in one visual span task (Logie, 1996), a subject is presented with a matrix of blocks for a brief time. Some of the blocks are filled in, and others are unfilled. After a brief delay, the matrix is represented with one block changing from filled to unfilled (or vice versa). The participant's task is to identify the changed block. This task is relatively easy if the matrix consists of few blocks but becomes increasingly difficult as the size of the matrix increases. The matrix size at which the subject can no longer reliably identify the changed block is taken as the upper bound of the storage capacity of the visuospatial sketchpad.

The phonological loop and sketchpad are subject to dual-task interference, another of the ways in which the subsystems of working memory can be characterized as capacity-limited resources. In the case of these subsystems, the limitations are most clearly exhibited for distracter tasks requiring the same working memory resource. For example, if subjects simultaneously carry out a digit span task and a verbal distracter task (both tasks that draw on the phonological loop), the measure of capacity (i.e., digit span) is dramatically reduced relative to baseline. Alternatively, if digit span is carried out along with a distracter task requiring visual or spatial imagery (which should draw on the sketchpad and not the phonological loop), minimal reduction of digit span occurs. Visual span exhibits the opposite pattern of interference. A secondary task requiring visual or spatial imagery greatly reduces visual span, whereas a verbal secondary task produces much less of an effect. This pattern of selective interference provides part of the rationale for positing the two distinct storage systems (Logie, 1996). Furthermore, this demonstrates that the two subsystems are limited-capacity resources for specialized purposes or information types.

Although the phonological loop and visuospatial sketchpad can be related to the construct of attention via limited capacity, it is the central executive component of working memory that is most typically associated with attention. In contrast to the specialized subsystems, the central executive is a general, amodal processing resource that monitors and controls the actions of the working memory subsystems. Increasingly, the central executive is seen as playing the more general role of an attentional controller, prompting Baddeley (1993) to wonder whether working memory, particularly the central executive component, might be better labeled 'working attention.'

To assess the relationship between the central executive (and the entirety of working memory) and attentional control, it is useful to have a general measure of working memory capacity. These assessments do not solely measure the central executive, because the executive is assumed to regulate and control the other processes in the system rather than provide active storage of information itself. Measures of working memory are called complex span tasks because they seek to assess the joint processing and storage capacities of the whole system, in contrast with simple span tasks (like digit span) that predominantly measure passive storage of a single subsystem (such as the phonological loop). One example is the reading span task (Daneman and Carpenter, 1980) in which subjects read a series of sentences and simultaneously try to maintain the last word from each sentence. At the end of a set of sentences, the participant recalls the final words. The number of words recalled serves as the measure of working-memory span. This task requires both processing (for comprehension) and storage. A similar task is the operation span task (Engle, 2002), every trial of which consists of an equation and a word (e.g., "$4/2 - 3 = 6$? (yes or no) DOG"). The participant's task is to verify whether the equation is correct and remember the word for subsequent recall. At the end of a small set of trials (e.g., 2–7), the words are recalled (again serving as the measure of working memory span).

Working memory capacity, as measured in these tasks, correlates with a number of higher cognitive skills, such as language comprehension, reading ability, reasoning, and general intelligence (see Engle and Kane (2004), for a review). Importantly for the present purposes, working memory capacity also relates to the control of attention. As noted earlier, individuals with higher working memory spans are less distractible in dichotic listening tasks and exhibit greater control over inhibitory processes (e.g., Conway et al., 2001). Experimental manipulations of working memory capacity produce similar effects in selection and inhibition paradigms (deFockert et al., 2001; Engle and Kane, 2004; Lavie et al., 2004).

## 2.02.4 Attention and Episodic Memory

The preceding section focused on the relationship between attention and working memory. Returning to the quotations that began this chapter, we now turn to research on attention and long-term memory, beginning with episodic memory. The vast majority of research on long-term memory has focused on episodic (or explicit) memory, conscious recollection of the past on direct tests of memory such as recognition, free recall, and cued recall. Furthermore, most of this research on memory and attention examines the role of attention during encoding. The bulk of this research provides little challenge to the intuitive sense that attention is critical for long-term memory; that is, memory for a stimulus is negatively affected by manipulations of selective or divided attention. Rather, research in this domain typically examines whether some aspects of stimulus encoding might be less reliant on attention than others and whether any elements of episodic encoding can be thought of as being free of attentional influence. In addition, there has been recent interest in determining whether retrieval from episodic memory requires attention to the same degree as encoding.

### 2.02.4.1 Attention and Encoding

The deleterious effects of reduced attention during encoding have been amply documented from the earliest days of psychological research (Smith, 1895). This holds for manipulations of selective attention as well as dual-task manipulations meant to divide central attentional resources. Beginning with selective attention, the research on dichotic listening makes clear that memory for the content of material presented in the unattended channel is greatly diminished on explicit memory tests such as recognition and recall (Broadbent, 1971). Furthermore, it is often the case that there is no measurable episodic memory at all for ignored material. For example, Eich (1984) found that recognition memory was at chance for words presented in the ignored channel of a dichotic listening study. Of course, it is also clear from this early research that at least some rudimentary perceptual information about the unattended message persists. Even in studies with tight controls for covert attentional switching, subjects recall whether the ignored channel was human speech, a male or female voice, a tone, and so on, implying that some encoding of perceptual information occurs without selection (Lachter et al., 2004). On the other hand, it should also be noted that, even if perceptual information about ignored stimuli is encoded to some degree, the encoding of this information is enhanced by focused attention (Cowan, 1995).

Research on visual selective attention reveals similar results. For example, Wolford and Morrison (1980) developed a visual analogue to dichotic listening in which the study trials consisted of a word flanked by two digits (e.g., 3 DOG 5). In one condition, participants attended to the digits, judging if they were of the same parity (both odd or both even) or of different parity. Although the word was focally presented, it was not the object of attention. In another condition, participants attended to the word. Several blocks of trials were presented to fully accustom the participants to the encoding task. Later, participants were given a recognition test for the words. Not surprisingly, recognition memory was greater when participants attended to the words as opposed to the digits. In addition, when tested on words from the final study blocks (after practicing the parity judgment task over many trials), participants in the parity-judgment condition exhibited no recognition memory for the words. This is quite similar to dichotic listening results that imply that selective attention is critical for later long-term memory and may be absent in an unattended condition (Merikle and Reingold, 1991).

It is clear that selective attention to a stimulus enhances (and may be necessary for) long-term episodic memory for the stimulus. Substantial research has also been conducted to examine the role of central attentional resources in memory encoding, typically by using a dual-task paradigm (i.e., a divided-attention manipulation), in which encoding is carried out under full or divided attention conditions. For example, in the full attention condition, the participant might read a series of study words and attempt to memorize them for a later test. In the divided-attention condition, the participant attempts to read and memorize the study words while simultaneously carrying out a secondary task. The secondary tasks take on a number of forms but are all designed to compete for central attentional resources. For example, in the three-odd task, the participant hears a series of digits and signals whenever he/she detects a sequence of three odd numbers in a row. Alternatively, one might divide attention with a short-term memory load, in which the participant keeps in mind a set of digits or letters while reading and trying to memorize a set of study materials (the participant recalls the memory load at the end of the study trial to ensure that the material was kept in mind).

It is abundantly clear that dividing attention with tasks such as these degrades later memory on explicit tests, such as recognition or free and cued recall (e.g., Craik et al., 1996; Mulligan, 1998). It should be noted, however, that even quite demanding secondary tasks are unlikely to eliminate explicit memory (Mulligan, 1997, 1998). In addition, the effects of divided attention on encoding are graded: As the secondary task becomes more and more difficult, later memory for the study materials is reduced accordingly (e.g., Mulligan, 1997).

Much of the research in this area focuses on whether there are certain aspects of episodic memory that are more or less dependent on central attention. For example, Castel and Craik (2003) examined whether memory for item versus associative information has differential reliance on attention. Item memory refers to the recognition or recall of individual stimuli as having been present in some particular episode (e.g., the study phase of a memory experiment). Associative memory refers to memory for a newly formed association between stimuli. This goes beyond memory for which stimuli were present in a given context but requires remembering which stimuli were associated with one another. Castel and Craik argued that the formation of new associations requires binding processes that are carried out in prefrontal cortex and are highly dependent on central attention (e.g., Moscovitch, 2000). Consequently, these authors predicted that dividing attention during encoding should disrupt associative memory more than item memory. To test this prediction, participants were presented with pairs of study words under either full or divided attention (attention was divided with the three-odd task). Item memory was assessed by a recognition test for the second word of each pair. That is, participants merely had to remember whether the test word was presented during the study phase. Associative memory was assessed with a paired recognition test, using several types of test pairs. Some of the test pairs were identical to pairs on the study list (intact pairs), some test pairs consisted of two old words from different study pairs (rearranged pairs), and other test pairs contained one or two new words. On this test, participants try to recognize intact pairs from the study list, a discrimination requiring memory for a particular association formed during the encoding phase. Divided attention reduced accuracy in both of the item and associative tests, but as predicted, the deficit was substantially greater for associative recognition. Similar results are found on tests of context and order memory, tests that likewise require episodic binding of previously unrelated information (e.g., Troyer et al., 1999; Troyer and Craik, 2000).

Dual-process models of episodic memory, which propose two independent memory processes, recollection and familiarity (Jacoby, 1991; Yonelinas, 2002), are similar to the distinction between item and associative information. Recollection refers to consciously remembering both the specific test item and the context in which it occurred, whereas familiarity is an undifferentiated feeling that a stimulus was previously encountered. Recollection is assumed to entail a recall-like search process that is consciously controlled and intentional. Familiarity, however, is assumed to be unconscious and unintentional, reflecting processing fluency. Recollection is reliant on binding processes during encoding that associate items and their spatiotemporal context. This suggests that recollection should be quite sensitive to divided attention during encoding. Alternatively, familiarity is assumed to have much less reliance on associative processing, and consequently less reliance on attention. Several lines of research support these notions. First, different types of episodic tests show differential sensitivity to divided attention at encoding, with free recall being the most affected and recognition memory the least (e.g., Craik et al., 1996). Given that free recall is assumed to be heavily reliant on recollective search processes and recognition is more heavily influenced by familiarity, it makes sense that recall is more affected by divided attention than recognition. Second, methods used to tease apart recollection and familiarity within recognition memory (such as the process-dissociation and remember/know procedures) generally indicate that dividing attention during encoding has robust effects on later recollection but little effect on familiarity (see Yonelinas (2002) for a review).

### 2.02.4.2 Attention and Retrieval

Because the traditional view states that attention is critical for the *creation* of memory traces (e.g., James, 1890; Cherry, 1953; Broadbent, 1958; Norman, 1969), it is not surprising that the vast majority of the research on attention and episodic memory has focused on encoding. Interest in the role of attention in memory retrieval is a more recent development. In an early study on the topic, Baddeley et al. (1984) examined the effects of divided attention on both episodic encoding and retrieval using free-recall, cued-recall, and recognition memory tests. As one would expect, dividing attention during encoding decreased performance on all the memory tests. However, when attention was divided during retrieval there was little decrease in memory accuracy, leading Baddeley et al. to conclude that retrieval processes are relatively automatic.

Craik et al. (1996) likewise varied attention during encoding and during retrieval but came to somewhat different conclusions. Craik et al. used a secondary task that permitted two complementary assessments of the role of attention in memory retrieval. First, as in Baddeley et al. (1984), accuracy in the memory task was compared under the full and divided attention conditions. Second, performance on the secondary task in the divided-attention condition was compared with performance in this task when performed alone (in a baseline condition, in which the secondary task was the sole task). The first comparison indicates whether the secondary task has an effect on memory retrieval. The second comparison indicates whether memory retrieval has an effect on the secondary task. Such secondary task costs are a traditional way to measure whether a process (like memory retrieval) requires attention. The results of the first comparison were consistent with Baddeley et al. (1984): dividing attention during retrieval produced little decline in memory accuracy (of course, divided attention during encoding produced the typical reduction in memory performance, **Figure 3**). However, the second comparison indicated that performance in the secondary task was disrupted when paired with memory retrieval. This contradicts the proposal that retrieval processes are automatic. Rather, Craik et al. argued, retrieval processes make use of attentional resources (as evidenced by the secondary task costs) but proceed in an obligatory (or 'protected') manner (Naveh-Benjamin et al., 2000). Under this view, retrieval takes precedence over other ongoing activities, protecting retrieval accuracy from the deleterious effects of a secondary task.

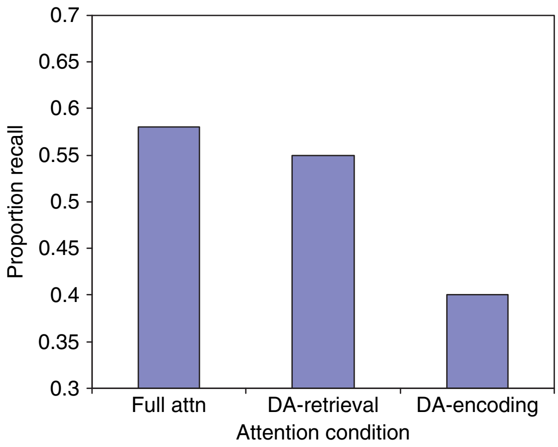


**Figure 3** Craik et al. (1996) found that dividing attention during encoding produced a substantial decrease in recall, whereas dividing attention during retrieval produced minimal effect. Full attn = full attention at both encoding and retrieval; DA-encoding = divided attention during encoding, full attention during retrieval; DA-retrieval = full attention during encoding, divided attention during retrieval.

Although Baddeley et al. (1984), Craik et al. (1996), and several other studies (see Craik (2001) for a review) found no effect of divided attention at retrieval on memory accuracy, such effects sometime emerge. Some studies report significant effects on free and cued recall without finding a comparable effect on recognition accuracy (e.g., Park et al., 1989; Anderson et al., 1998). In other studies, a significant decrement to recognition accuracy is reported (Fernandes and Moscovitch, 2000; Hicks and Marsh, 2000; Lozito and Mulligan, 2006). It is important to ascertain why such effects might be found.

Fernandes and Moscovitch (2000, 2003) have argued that memory retrieval is more likely to be disrupted when the secondary task and the memory task use the same type of materials. For example, Fernandes and Moscovitch (2000) used either a number-based or word-based secondary task as participants carried out a recall or recognition test for studied words. The number-based task did not disrupt test accuracy (consistent with Craik et al., 1996), whereas the word-based task significantly reduced memory accuracy. Although the results indicate a divided attention deficit in recognition, Fernandes and Moscovitch argued that decrements obtained were not caused by competition for central attentional resources but were, rather, a result of competition for word-specific representational systems. Fernandes and Moscovitch labeled this a material-specific interference effect.

Hicks and Marsh (2000), in contrast, posited that competition for central resources can also lead to a divided attention effect under certain conditions. They based this claim on the dual-process model described above, arguing that search-based recollection processes should be disrupted by a secondary task, whereas familiarity processes should be less susceptible. Consequently, encoding conditions that produce higher levels of recollection should exhibit divided-attention effects. Hicks and Marsh had participants either read or generate words during encoding under the standard assumption that generation enhances later recollection. During the recognition test, memory accuracy was reduced by divided attention in the generate condition but not in the read condition. Lozito and Mulligan (in press) also found significant divided-attention effects on both conceptual and perceptual recognition tests, converging on a similar conclusion: Memory retrieval that is recollective in nature is susceptible to divided-attention effects during retrieval. In light of the results of Fernandes and Moscovitch (2000), it is critical to note that the secondary tasks of Hicks and Marsh and of Lozito and Mulligan used numbers, whereas the memory test used words, implying that the divided-attention effect is general (i.e., implicating central attention), rather than material specific.

## 2.02.5 Attention and Other Forms of Long-Term Memory

### 2.02.5.1 Attention and Implicit Memory

At the outset of this chapter we differentiated between explicit (episodic, recollective, intentional, conscious) memory and implicit (unconscious, unintentional, nonepisodic) memory. Explicit memory is typically measured with traditional memory tests, such as recognition and free and cued recall, in which participants are directed to think back about a prior event and report on it. Implicit memory tests simply require participants to perform a task (e.g., completing word fragments, generating category examples) without reference to any prior experience. Memory for prior events is inferred from the increased ability to complete, generate, identify, or otherwise process recently presented stimuli. The enhanced processing is called priming.

The principles that govern implicit and explicit memory appear to differ in a number of ways, as evidenced by striking population and functional dissociations (*See* Chapter 2.33; Roediger and McDermott, 1993; Mulligan, 2003b). Coupled with neuroimaging evidence (e.g., Schacter and Badgaiyan, 2001), these dissociations indicate separable components of memory underlying implicit and explicit memory phenomena. Given the centrality of attention in theories of memory encoding and the rather uniform effects of divided attention on episodic memory, it is important to evaluate the role of attention in implicit memory.

With regard to manipulations of selective attention, the results are quite clear: Directing attention away from a stimulus diminishes the amount of priming detected (e.g., Eich, 1984; Bentin et al., 1998; Crabb and Dark, 1999; Mulligan and Hornstein, 2000). This implies that selective attention is necessary for robust levels of priming. A separate question is whether implicit memory can arise in the absence of attention. This question is a matter of some debate. A study by Eich (1984) indicated this possibility. In this dichotic listening experiment, subjects shadowed a prose passage presented to one ear while word pairs were presented in the other ear. Each word pair consisted of a homophone and a word biasing its less common meaning (e.g., taxi-FARE). Subjects showed no explicit recognition for these words. In an implicit test condition, subjects were given a spelling test for aurally presented words. This test contained the homophones presented during the shadowing task as well as a control set of homophones. The subjects were more likely to choose the uncommon spelling for homophones from the ignored channel than for the control homophones, demonstrating above-chance priming for the word pairs presented in the irrelevant channel. This has been taken as evidence of implicit memory for unattended stimuli. It should be noted that, when the word pairs were presented to the shadowed ear, even greater levels of priming resulted. So Eich's results demonstrate reduced priming for the ignored versus attended channel, coupled with above-chance priming for the material presented in the ignored ear. Merikle and Reingold (1991) showed a similar pattern of results for visual selective attention.

Although the results of Eich (1984) were impressive and indicate that implicit memory has less reliance on selective attention than does explicit memory, there is reason to wonder whether these results represent implicit memory for unattended material. Wood et al. (1997) suggested that the presentation rate of the material in Eich's (1984) study was too slow to preclude rapid, covert switches of attention. As noted in the earlier discussion of dichotic listening, there is always the concern of attentional slippage. Wood et al. investigated this issue by varying the speed with which the attended materials was presented. At the slower rate used by Eich, Wood et al. found the same results: chance-level recognition coupled with above-chance priming on the spelling task. However, at the faster rate (a rate at which subjects could still successfully shadow), priming in the spelling task was not above chance. Wood et al. argued that a faster rate in the attended channel renders the shadowing task more attention demanding and diminishes the likelihood of covert (and undetected) switches of attention to the putatively unattended channel. Consequently, even though the unattended materials were presented at the same slow rate as in the Eich study, no priming was found. This argues against the notion that implicit memory is found for unattended stimuli. Similarly, Berry et al. (2006) recently failed to replicate Merikle and Reingold's results with visual selective attention, strengthening the concern about implicit memory in the absence of attention.

A related line of research has used dual-task paradigms to examine the role of central attention resources in implicit memory. As with selection attention studies, initial studies implied important differences in the role of attention in implicit and explicit memory, with later studies modifying this conclusion. Consider an experiment by Parkin and Russo (1990), in which participants named pictures of everyday objects during the study phase. In the full-attention condition, this was the sole task. In the divided-attention condition, participants named the pictures and carried out a tone-monitoring task, in which a series of tones were categorized as high, medium, or low. Participants were later given an explicit test, in which they recalled the names of the pictures, or an implicit test, in which they identified fragmented pictures. Priming in this task is indicated by identification of studied (or old) pictures at lower levels of clarification than the new pictures. As would be expected, recall was greatly diminished by divided attention. However, the amount of priming on the picture-fragment task was essentially the same for the full- and divided-attention conditions. Several other studies produced similar results (see Jacoby et al., 1989; Parkin et al., 1990; Russo and Parkin, 1993; Mulligan and Hartman, 1996; Schmitter-Edgecombe, 1996a,b), giving rise to the claim that implicit memory has little reliance on attention and largely reflects automatic encoding processes (e.g., Jacoby et al., 1989, 1993; Parkin et al., 1990; Parkin and Russo, 1990; Bentin et al., 1995; Isingrini et al., 1995; Aloisi et al., 2004).

The notion that implicit memory reflects automatic encoding processes has not withstood subsequent research, however (see Mulligan and Brown (2003) for a review). First, this initial research focused on perceptually based priming tasks (such as perceptual identification and word and picture fragment completions), in which degraded or partial perceptual cues guide memory retrieval. Implicit memory may also be assessed with conceptually based tests in which memory retrieval is guided by conceptual cues, such as category names or associates. Mulligan and Hartman (1996; Mulligan, 1997, 1998) demonstrated that conceptual priming is quite sensitive to division of attention during encoding. Second, even perceptually based implicit tests have proven susceptible to divided-attention manipulation under some conditions. For example, Mulligan (2003a) found that a divided-attention task requiring frequent response selection affected perceptual priming, whereas a divided-attention task requiring less frequent response selection left priming unaffected.

To summarize the results, it is now clear that implicit memory is generally affected by a variety of selective- and divided-attention manipulations, indicating that implicit memory relies on both selective attention and central attentional resources. In addition, the effects of these attention manipulations are generally larger on explicit than implicit memory. At present, the results indicate that implicit and explicit memory differ quantitatively rather than qualitatively in terms of their reliance on attention. Both forms of memory rely on attention (in both the selective and central-resources senses), but explicit memory appears to rely on attention more heavily (see Mulligan, 2003a, for speculation as to why).

### 2.02.5.2 Attention and Procedural Learning

Procedural learning encompasses the acquisition of perceptual, motor, and cognitive skills and is another form of nonconscious memory. Skill acquisition is characterized by gradual improvements in performance over many sessions of practice. To isolate processes of procedural learning and make it amenable to experimental analysis, researchers have typically turned to a small set of laboratory tasks. The most prominent example is the serial reaction time (SRT) test. In this test, participants identify the location of a target as it moves among a fixed set of (usually four to seven) locations by pressing the key that corresponds to each new location. Embedded in the sequence of locations is a repeating pattern. Reaction times gradually decrease over hundreds or thousands of trials. Procedural learning is assessed in a transfer block in which the pattern is no longer present. An increase in reaction times indicates that something about the repeating pattern had been learned. Another commonly used task is the artificial grammar (AG) learning task developed by Reber (1967). In this task, participants are presented with strings of elements (e.g., letters) that were produced by a complex set of rules – the underlying grammar – that dictates the order in which the elements may occur. After exposure to the learning set, a new set of strings is presented, some of which are consistent with the grammar (i.e., these are strings generated by the grammar), and others that violate the grammar. The participant's task is to categorize the test strings as grammatical or nongrammatical. Above-chance accuracy on this test in the absence of verbalizable knowledge of the grammatical rules is usually taken as evidence of implicit learning of (at least some aspects of) the underlying grammar (see Dienes and Berry, 1997, for a review).

The bulk of the research on attention and procedural learning has examined the role of central attentional resources, using dual-task paradigms. In an early study, Nissen and Bullemer (1987) reported that dividing attention during learning eliminated procedural learning in the SRT task. The dual task used in that study was a tone counting task, in which participants heard high and low tones and kept a running count of the number of low tones. However, there is evidence that the tone-counting task may disrupt procedural learning by interfering with the timing or organization of responses in the SRT task rather than through its demands on central attention (e.g., Stadler, 1995). An arguably less problematic secondary task, the symbol counting task, produces similar effects, disrupting procedural learning relative to a full-attention condition (e.g., Shanks and Channon, 2002; Shanks et al., 2005). Research using the AG task produces similar results. Procedural learning in this task is reduced by a concurrent decision task (Dienes et al., 1991). The learning of complex motor skills has a similar reliance on attention (Wulf and Prinz, 2001). Thus, the acquisition of procedural skills appears to rely on central attentional mechanisms. However, the expression of highly learned skills may not. For example, Helman and Berry (2003) found that dividing attention during the final test in an AG task produced no effect on the expression of procedural information that was initially acquired in a full attention condition. Eversheim and Bock (2001) present a single study of procedural learning, which reveals the typical pattern of results across early acquisition trials and later expression of a practiced skill. These authors used a tracking task in which the visual feedback had been reversed. Over the early trials of the tracking task, performing a secondary task greatly diminished the rate of improvement. However, after extensive practice with the task, a dual-task condition produced little decrement in performance. That is, the acquisition of this new perceptual-motor skill was harmed by distraction, whereas the expression of the attained skill was little disrupted by divided attention.

Although the majority of the relevant studies examined central-attentional resources, a few have examined the relationship between selective attention and procedural learning. Perhaps not surprisingly, most have concluded that procedural learning requires selective attention to the stimuli of the learning task (e.g., Jiang and Chun, 2001; Turk-Browne et al., 2005; see also Wulf and Prinz, 2001).

## 2.02.6 Concluding Comments

This chapter began with quotations from James and Ebbinghaus articulating the traditional view that attention is critically important for memory. Modern researchers differentiate among multiple forms of both memory and attention, which has allowed a more fine-grained analysis of this relationship. We have seen the ways in which attention is intertwined with the concept of working memory, so much so that aspects of working memory (i.e., the central executive) are sometimes equated with central attention. It is also apparent that attention is critical for acquisition in long-term memory. This is especially clear with regard to episodic memory, although reliance on attention might be greater for certain aspects of episodic encoding (e.g., associative information) than for others (e.g., item information). Furthermore, recent research highlights the importance of attention during encoding for nonepisodic forms of memory, such as implicit and procedural memory phenomena. It is only in the case of long-term memory retrieval that the role of attention is debated. Retrieval from episodic memory appears to be attention demanding, albeit less so than memory encoding. In contrast, retrieval in procedural memory, especially of well-learned skills, is much less dependent on attention. Finally, there is little research on the role of attention in implicit memory, an area in need of systematic research.

## References


Aloisi BA, McKone E, and Huebeck BG (2004) Implicit and explicit memory performance in children with attention deficit/hyperactivity disorder. *Br. J. Dev. Psychol.* 22: 275–292.

Anderson ND, Craik FIM, and Naveh-Benjamin M (1998) The attentional demands of encoding and retrieval in younger and older adults: I. Evidence from divided attention costs. *Psychol. Aging* 13: 405–423.

Ashby FG, Alfonso-Reese LA, Turken AU, and Waldron EM (1998) A neuropsychological theory of multiple systems in category learning. *Psychol. Rev.* 105: 442–481.

Atkinson RC and Shiffrin RM (1968) Human memory: A proposed system and its control processes. In: Spence KW and Spence JT (eds.) *The Psychology of Learning and Motivation,* Vol. 2, pp. 89–195. New York: Academic Press.

Baddeley A (1986) *Working Memory*. Oxford: Clarendon Press.

Baddeley AD (1993) Working memory or working attention? In: Baddeley A and Weiskrantz L (eds.) *Attention: Selection, Awareness, and Control: A Tribute to Donald Broadbent*, pp. 152–170. Oxford: Oxford University Press.

Baddeley AD (2002) Is working memory still working? *Eur. Psychol.* 7: 85–97.

Baddeley A, Lewis V, Eldridge M, and Thomson N (1984) Attention and retrieval from long-term memory. *J. Exp. Psychol. Gen.* 113: 518–540.

Bentin S, Kutas M, and Hillyard SA (1995) Semantic processing and memory for attended and unattended words in dichotic listening: Behavioral and electrophysiological evidence. *J. Exp. Psychol. Hum. Percept. Perform.* 21: 54–67.

Bentin S, Moscovitch M, and Nirhod O (1998) Levels of processing and selective attention effects in encoding in memory. *Acta Psychol. (Amst.)* 98: 311–341.

Berry CJ, Shanks DR, and Henson RNA (2006) On the status of unconscious memory: Merikle and Reingold (1991) revisited. *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 925–934.

Broadbent DE (1958) *Perception and Communication*. London: Pergamon Press.

Broadbent DE (1971) *Decision and Stress*. San Diego, CA: Academic Press.

Castel AD and Craik FIM (2003) The effects of aging and divided attention on memory for item and associative information. *Psychol. Aging* 18: 873–885.

Cherry EC (1953) Some experiments on the recognition of speech with one and with two ears. *J. Acoust. Soc. Am.* 26: 554–559.

Conway ARA, Cowan N, and Bunting MF (2001) The cocktail party phenomenon revisited: The importance of working memory capacity. *Psychonom. Bull. Rev.* 8: 331–335.

Corteen RS and Dunn D (1974) Shock-associated words in a nonattended message: A test for momentary awareness. *J. Exp. Psychol.* 102: 1143–1144.

Corteen RS and Wood B (1972) Autonomic responses to shock associated words in an unattended channel. *J. Exp. Psychol.* 94: 308–313.

Cowan N (1995) *Attention and Memory: An Integrated Framework*. New York: Oxford University Press.

Crabb B and Dark V (1999) Perceptual implicit memory requires attentional encoding. *Mem. Cogn.* 27: 267–275.

Craik FIM (2001) Effects of dividing attention on encoding and retrieval processes. In: Roediger HL, Nairne JS, Neath I, and Surprenant AM (eds.) *The Nature of Remembering: Essays in Honor of Robert G. Crowder*, pp. 55–68. Washington DC: American Psychological Association.

Craik FIM, Govoni R, Naveh-Benjamin M, and Anderson ND (1996) The effects of divided attention on encoding and retrieval processes in human memory. *J. Exp. Psychol. Gen.* 125: 159–180.

Daneman M and Carpenter PA (1980) Individual differences in working memory and reading. *J. Verbal Learn. Verbal Behav.* 19: 450–466.

Dawson ME and Schell AM (1982) Electrodermal responses to attended and nonattended significant stimuli during dichotic listening. *J. Exp. Psychol. Hum. Percept. Perform.* 8: 315–324.

deFockert JW, Rees G, Frith CD, and Lavie N (2001) The role of working memory in visual selective attention. *Science* 291: 1803–1806.

Deutsch JA and Deutsch D (1963) Attention: Some theoretical considerations. *Psychol. Rev.* 70: 80–90.

Dienes Z and Berry DC (1997) Implicit learning: Below the subjective threshold. *Psychonom. Bull. Rev.* 4: 3–23.

Dienes Z, Broadbent D, and Berry DC (1991) Implicit and explicit knowledge bases in artificial grammar learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 17: 875–887.

Duncan J (1999) Converging levels of analysis in the cognitive neuroscience of visual attention. In: Humphreys GW, Duncan J, and Treisman A (eds.) *Attention, Space, and Action: Studies in Cognitive Neuroscience*, pp. 112–129. New York: Oxford.

Duncan J, Martens S, and Ward R (1997) Restricted attentional capacity within but not between sensory modalities. *Nature* 379: 808–810.

Ebbinghaus H (1885) *Memory: A Contribution to Experimental Psychology*. New York: Columbia University. [Reprinted 1964, New York: Dover.]

Eich E (1984) Memory for unattended events: Remembering with and without awareness. *Mem. Cogn.* 12: 105–111.

Engle RW (2002) Working memory capacity as executive attention. *Curr. Dir. Psychol. Sci.* 11: 19–23.

Engle RW and Kane MJ (2004) Executive attention, working memory capacity, and a two-factor theory of cognitive control. In: Ross BH (ed.) *The Psychology of Learning and Motivation,* vol. 44, pp. 145–199. New York: Elsevier Science.

Eversheim U and Bock O (2001) Evidence for processing stages in skill acquisition: A dual-task study. *Learn. Mem.* 8: 183–189.

Fernandes MA and Moscovitch M (2000) Divided attention and memory: Evidence of substantial interference effects both at retrieval and encoding. *J. Exp. Psychol. Gen.* 129: 155–176.

Fernandes MA and Moscovitch M (2003) Interference effects from divided attention during retrieval in younger and older adults. *Psychol. Aging* 18: 219–230.

Freiwald WA and Kanwisher N (2004) Visual selective attention: insights from brain imaging and neurophysiology. In: Gazzaniga MS (ed.) *The Cognitive Neurosciences,* 3rd edn., pp. 575–588. Cambridge, MA: MIT Press.

Helman S and Berry DC (2003) Effects of divided attention and speeded responding on implicit and explicit retrieval of artificial grammar knowledge. *Mem. Cogn.* 31: 703–714.

Hicks JL and Marsh RL (2000) Towards specifying the attentional demands of recognition memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1483–1498.

Holender D (1986) Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: A survey and appraisal. *Behav. Brain Sci.* 9: 1–23.

Humphreys GW and Samson D (2004) Attention and the frontal lobes. In: Gazzaniga MS (ed.) *The Cognitive Neurosciences,* 3rd edn., pp. 607–618. Cambridge, MA: MIT Press.
Isingrini M, Vazou F, and Leroy P (1995) Dissociation between implicit and explicit memory tests: Effects of age and divided attention on category exemplar generation and cued recall. *Memory Cogn.* 23: 462–467.
Jacoby LL (1991) A process dissociation framework: Separating automatic from intentional uses of memory. *J. Mem. Lang.* 30: 513–541.
Jacoby LL, Toth JP, and Yonelinas AP (1993) Separating conscious and unconscious influences of memory: Measuring recollection. *J. Exp. Psychol. Gen.* 122: 1–16.
Jacoby LL, Woloshyn V, and Kelley C (1989) Becoming famous without being recognized: Unconscious influences of memory produced by divided attention. *J. Exp. Psychol. Gen.* 118: 115–125.
James W (1890) *The Principles of Psychology*. London: MacMillan.
Jiang Y and Chun MM (2001) Selective attention modulates implicit learning. *Q. J. Exp. Psychol.* 54A: 1105–1124.
Johnston JC, McCann RS, and Remington RW (1995) Chronometric evidence for two types of attention. *Psychol. Sci.* 6: 365–369.
Lachter J, Forster KI, and Ruthruff E (2004) Forty-five years after Broadbent (1958): Still no identification without attention. *Psychol. Rev.* 111: 880–913.
Lackner JR and Garrett MF (1972) Resolving ambiguity: Effects of biasing context in the unattended ear. *Cognition* 1: 359–372.
Lavie N, Hirst A, deFockert JW, and Viding E (2004) Load theory of selective attention and cognitive control. *J. Exp. Psychol. Gen.* 135: 339–354.
Logie RH (1996) The seven ages of working memory. In: Richardson JTE, Engle RW, Hasher L, et al. (eds.) *Working Memory and Human Cognition*, pp. 31–65. New York: Oxford University Press.
Lozito JP and Mulligan NW (2006) Exploring the role of attention during memory retrieval: Effects of semantic encoding and divided attention. *Mem. Cogn.* 34: 986–998.
Maddox WT (2002) Learning and attention in multidimensional identification and categorization: Separating low-level perceptual processes and high-level decisional processes. *J. Exp. Psychol. Learn. Mem. Cogn.* 28: 99–115.
Miller GA (1956) The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychol. Rev.* 63: 81–97.
Merikle P and Reingold E (1991) Comparing direct (explicit) and indirect (implicit) measures to study unconscious memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 17: 224–233.
Moray N (1959) Attention in dichotic listening: Affective cues and the influence of instructions. Quarterly *J. Exp. Psychol.* 11: 56–60.
Moscovitch M (2000) Theories of memory and consciousness. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 609–625. New York: Oxford University Press.
Mulligan NW (1997) Attention and implicit memory: The effects of varying attentional load on conceptual priming. *Mem. Cogn.* 25: 11–17.
Mulligan NW (1998) The role of attention during encoding on implicit and explicit memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 24: 27–47.
Mulligan NW (2003a) Effects of cross-modal and intra-modal division of attention on perceptual implicit memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 262–276.
Mulligan NW (2003b) Memory: Implicit versus explicit. In: Nadel L (ed.) *Encyclopedia of Cognitive Science*, pp. 1114–1120. London: Nature Publishing Group/MacMillan.
Mulligan NW and Brown AS (2003) Attention and implicit memory. In: Jiminez L (ed.) *Attention, Consciousness, and Learning*, pp. 297–334. Amsterdam: John Benjamins Publishing.
Mulligan NW and Hartman M (1996) Divided attention and indirect memory tests. *Mem. Cogn.* 24: 453–465.
Mulligan NW and Hornstein SL (2000) Attention and perceptual priming in the perceptual identification task. *J. Exp. Psychol. Learn. Mem. Cogn.* 24: 27–47.
Naveh-Benjamin M, Craik FIM, Gavrilescu D, and Anderson ND (2000) Asymmetry between encoding and retrieval processes: Evidence from divided attention and a calibration analysis. *Mem. Cogn.* 28: 965–976.
Nissen MJ and Bullemer P (1987) Attentional requirements of learning: Evidence from performance measures. *Cogn. Psychol.* 19: 1–32.
Norman DA (1968) Toward a theory of memory and attention. *Psychol. Rev.* 75: 522–536.
Norman DA (1969) *Memory and Attention: an Introduction to Human Information Processing*. New York: Wiley and Sons, Inc.
Park DC, Smith AD, Dudley WN, and Lafronza VN (1989) Effects of age and a divided attention task presented during encoding and retrieval on memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 1185–1191.
Parkin AJ, Reid TK, and Russo R (1990) On the differential nature of implicit and explicit memory. *Mem. Cogn.* 18: 507–514.
Parkin AJ and Russo R (1990) Implicit and explicit memory and the automatic/effortful distinction. *Eur. J. Cogn. Psychol.* 2: 71–80.
Pashler HE (1998) *The Psychology of Attention*. Cambridge, MA: MIT Press.
Posner MI and Petersen SE (1990) The attention system of the human brain. *Annu. Rev. Neurosci.* 13: 25–42.
Reber AS (1967) Implicit learning of artificial grammars. *J. Verbal Learn. Verbal Behav.* 6: 855–863.
Roediger HL and McDermott KB (1993) Implicit memory in normal human subjects. In: Boller F and Grafman J (eds.) *Handbook of Neuropsychology,* vol. 8, pp. 63–131. Amsterdam: Elsevier.
Russo R and Parkin AJ (1993) Age differences in implicit memory: More apparent than real. *Mem. Cogn.* 21: 73–80.
Schacter DL and Badgaiyan RD (2001) Neuroimaging of priming: New perspectives on implicit and explicit memory. *Curr. Dir. Psychol. Sci.* 10: 1–4.
Schacter DL, Wagner AD, and Buckner RL (2000) Memory systems of 1999. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook on Memory*, pp. 627–643. New York: Oxford University Press.
Schmitter-Edgecombe M (1996a) Effects of divided attention on implicit and explicit memory performance following severe closed head injury. *Neuropsychology* 10: 155–167.
Schmitter-Edgecombe M (1996b) The effects of divided attention on implicit and explicit memory performance. *J. Int. Neuropsychol. Soc.* 2: 111125.
Shanks DR and Channon S (2002) Effects of a secondary task on ''implicit'' sequence learning: Learning or performance? *Psychol. Res.* 66: 99–109.
Shanks DR, Rowland LA, and Ranger MS (2005) Attentional load and implicit sequence learning. *Psychol. Res.* 69: 369–382.
Smith WG (1895) The relation of attention to memory. *Mind* 4: 47–73.
Stadler MA (1995) Role of attention in sequence learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 674–685.
Treisman AM (1960) Contextual cues in selective listening. Quarterly *J. Exp. Psychol.* 12: 242–248.
Treisman AM (1964) Verbal cues, language and meaning selective attention. *Am. J. Psychol.* 77: 206–219.

Troyer AK and Craik FIM (2000) The effects of divided attention on memory for items and their context. *Can. J. Exp. Psychol.* 54: 161–171.
Troyer AK, Winocur G, Craik FIM, and Moscovitch M (1999) Source memory and divided attention: Reciprocal costs to primary and secondary tasks. *Neuropsychology* 13: 467–474.
Tulving E (2002) Episodic memory: From mind to brain. *Annu. Rev. Psychol.* 53: 1–25.
Turk-Browne NB, Junge J, and Scholl BJ (2005) The automaticity of visual statistical learning. *J. Exp. Psychol. Gen.* 134: 552–564.
Wickens CD (1984) *Engineering Psychology and Human Performance*. Columbus, OH: Merrill.
Wolford G and Morrison F (1980) Processing of unattended visual information. *Mem. Cogn.* 8: 521–527.
Wood NL, Stadler MA, and Cowan N (1997) Is there implicit memory without attention? A re-examination of task demands in Eich's (1984) procedure. *Mem. Cogn.* 25: 772–779.
Wulf G and Prinz W (2001) Directing attention to movement effects enhances learning: A review. *Psychonom. Bull. Rev.* 8: 648–660.
Yates FA (1966) *The Art of Memory*. Chicago: University of Chicago Press.
Yonelinas AP (2002) The nature of recollection and familiarity: A review of 30 years of research. *J. Mem. Lang.* 46: 441–517.

# 2.03 Sensory Memory

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## 2.03.1 Introduction

Sensory memory refers to the short-lived memory for sensory details of events. This can include how things looked, sounded, felt, smelled, and tasted. To some extent, this type of information must persist in long-term memory. It allows us to recognize a familiar voice over the telephone or to recognize the taste of a favorite food. However, the human information processing system seems to be designed in such a way that the richness of sensory memories is quickly lost, leaving behind more categorized memories. For example, when one hears or reads a sentence, the gist is strongly saved but the exact manner in which the material was presented is more quickly lost; verbatim wording is readily accessible only for the most recent phrase, and it is incomplete even for that phrase (Sachs, 1967; Jarvella, 1970). Physical features of stimuli do leave long-term memory traces that influence later behavior (Kolers, 1974; Cowan, 1984; Weldon et al., 1995), but these may lack the fine-grained subtlety of short-lived sensory memories. Sensory memory is typically distinguished from mental imagery, which can include sensory-like qualities but is typically less detailed. For example, one may form an image of a U.S. penny (one-cent coin), but it is distinguished from a sensory memory in its vagueness, such as not really knowing which way Lincoln's head faces.

It has long been recognized that at least some sorts of sensory memory operate in a manner that is different from other forms of memory. In classic research on attention, subjects were asked to repeat a message presented to one ear and ignore a conflicting message presented to the other ear concurrently. Although they could recall little of the message presented to the ear to be ignored, when the task ended the last few words of that message often could be recalled (Broadbent, 1958). This suggested that the information in the unattended message was held temporarily in a form that soon would be lost if it were not attended. A natural way to understand that phenomenon is that the temporary storage consists of sensory information and a longer-lasting record can be saved only if that sensory information is attended before it fades away, which allows the formation of memory for the words that were spoken.

Sperling (1960) carried out a classic study that dramatically illustrated the difference between sensory and abstract forms of memory for a recent event. Subjects saw a briefly presented array with three rows of characters and then received a tone indicating whether the top, middle, or bottom row should be recalled (a partial-report cue). If the tone was presented soon enough, almost all characters in the designated row could be recalled, provided that there were four or fewer characters in the row. As the delay between the array and the tone cue was increased, performance diminished, quickly at first and then more slowly, curving down to a steady level (asymptote) within 1 s. By that point, the cue came too late to be of use, and subjects could remember only as many characters as one would expect if the limit were about four characters retained from the entire display. This pattern of results could be accounted for on the basis of two types of memory: a sensory memory that held the entire display like a snapshot for a very short time, even though the number of characters was far too large to be attended at once, and a more abstract memory that could hold only about four items. The partial-report cue could influence which part of the sensory memory was transferred to an abstract form and then reported, but the cue had to be presented before the sensory memory faded.

One can see from this finding that an understanding of sensory memory is critical for an understanding of performance on memory tests. Even if one is trying to assess the availability of abstract forms of memory, the contribution of sensory memory must be either eliminated or taken into account. Beyond that, sensory memory is an important aspect of our conscious experience of the outside world, as we will see.

One thing that makes sensory memory controversial is that the boundaries between it and other types of memory are debatable. By some accounts, there is a distinction between sensory storage that comes before perception and postperceptual storage (Massaro and Loftus, 1996). It does appear that there are two phases of temporary memory for stimulus qualities: a brief phase that seems like a continuation of the stimulus for about a quarter second, and a second phase that seems like a vivid recollection for some seconds (Massaro, 1975a; Cowan, 1984, 1988, 1995). However, one could argue that the process of perception begins quite rapidly in the brain, and that the first phase of memory for sensation is already part of perception. When this brief memory begins to fade away, it is not the same thing as a picture becoming hazy or indistinct, as if viewed through a fog. Instead, it is as if different features of each object can be lost separately. In Sperling's (1960) type of procedure, for example, the errors that crop up as the partial-report cue is delayed (or omitted) appear to be primarily location errors, in which a character is reported at the wrong location rather than forgotten completely (Townsend, 1973; Mewhort et al., 1981; Irwin and Yeomans, 1986). Consistent with this, a great deal of neurological research suggests that different features of an object, such as its identity versus its location, are perceived using different neural subsystems (in vision: Haxby et al., 1991; in hearing: Alain et al., 2001; in touch: Pons et al., 1992), and that perception of an object therefore requires a subsequent integration of these features. Sensory memory could include a constellation of features that have not necessarily been integrated. The full integration of these features into objects could require attention (Treisman and Gelade, 1980), which could result in a nonsensory type of memory.

It also may be that the brief sort of sensory memory is not truly a memory as such but, rather, a side effect of perceptual processing. The difference is that the neural effect of a stimulus giving rise to sensation begins before the stimulus ends and, for very brief stimuli, may not even reach a peak until some time after the stimulus has ended. The duration of this sensory memory appears longer for less intense stimuli. Such findings suggest that the sensory persistence of the stimulus may reflect conscious access to neural processes involved in perception (cf. Weichselgartner and Sperling, 1985; Dixon and Di Lollo, 1994; Massaro and Loftus, 1996; Loftus and Irwin, 1998).

Given such debates, it is important to back up and examine the distinctions regarding sensory memory that often are taken as its defining characteristics.

## 2.03.2 Defining Characteristics of Sensory Memory

### 2.03.2.1 Memory for Stimuli As Opposed to Ideas

Consider how the perception of a newborn infant must differ from that of an adult: it differs in many ways, but one important difference is as follows. The infant has a range of sensory experiences, but there is not yet any way to attach significance or meaning to most of those experiences. An adult does have meanings, or ideas, to attach to experiences. For example, if an American adult sees a red octagon, it may remind him or her of a traffic stop sign. Yet it seems reasonable to believe that there is perception and memory of the shape and color that can be separated from its meaning. That may not be exactly true, inasmuch as it is difficult for people to remember or perhaps even to perceive objects without some influence of their knowledge that apples are red, grass is green, and so on (Bartleson, 1960; Ratner and McCarthy, 1990). After identification of a stimulus and its meaning has taken place, there may be neural feedback to the parts of the brain that perceive sensations. Nevertheless, to a first approximation, we can think of sensory memory as the memory for the knowledge-free, sensation-based characteristics of stimuli that resemble what a newborn would perceive. If it turns out to be impossible to think of sensory memory in this way, the postulation of a distinction between sensory and nonsensory forms of memory may have to be weakened.

#### 2.03.2.2 Memory for Information More Fine-Grained Than a Familiar Category

A critical step in perception is categorization: gaining the knowledge that a particular stimulus is an example of items in a certain category, whether or not one knows a verbal label for that category. For example, one can perceive two successive piano notes as coming from different tone categories even if one does not know or remember the names of those categories. Sensory memory is typically viewed as coming before that step of categorization. As a result, it can include fine details that distinguish items within a category, such as differences in tone frequency too small to change the identity of the note, except to make it slightly out of tune (Keller et al., 1995), differences between two slightly different pronunciations of the same vowel (Pisoni, 1973), or differences between two slightly different shades of the same color (Massaro, 1975a). In each case, if slightly different stimuli are presented in close succession (ideally within about 250 ms of each other), the sensory memory of the first stimulus can be compared to the second stimulus with good acuity. This characteristic could be important, as when one is trying to learn exactly how to imitate a word spoken in an unfamiliar language or, in infants, learning language in the first place.

#### 2.03.2.3 Memory Even for Unattended Stimuli

As mentioned in the introduction, the concept of sensory memory arose to explain how people can briefly retain more information than they can process. The concept of a short-lived sensory memory for unattended information was present in the selective listening procedure (Broadbent, 1958) and the partial-report procedure using visual arrays (Sperling, 1960). Darwin et al. (1972) brought these two lines of research together by constructing an auditory analogue of Sperling's procedure. In this analogue, an array of three simultaneous spoken characters presented to left, center, and right spatial locations was followed by a second such array and then a test for the information presented at one location. Similar findings were obtained using arrays of tones (Treisman and Rostron, 1972; Rostron, 1974).

In the auditory studies, it was not possible to present 12 or more simultaneous stimuli as Sperling (1960) did in the visual modality. Consequently, it is possible that subjects were able to carry out a perceptual analysis of the sounds. Nevertheless, other evidence suggests that the perceptual analysis is incomplete and that the items need not have received full attention to have been remembered in the procedure of Darwin et al. (1972). Cowan et al. (1990) carried out a procedure in which nine syllables (*bee, bih, beh, dee, dih, deh, gee, gih, geh*) were presented at random intervals through headphones while the subject ignored them and silently read a novel. When a light signal occasionally appeared, the subject was to stop reading and identify the last spoken syllable, which occurred 1, 5, or 10 s ago. Generally, performance was good at a 1-s retention interval and decreased dramatically across the longer intervals. However, in an experiment in which subjects had to monitor the speech stream while reading (pushing a button if *dih* was presented), there was no forgetting across retention intervals, even though the monitoring task was performed correctly on only 60% of the trials. In another experiment, the reading was whispered by the subject and recorded so that diversions in attention away from the reading could be observed (as 1-s pauses in reading). It was found that consonant perception was much better on trials in which there were diversions of attention while the target syllable was presented. The sensory form of memory may only be adequate for vowel perception, and memory for consonants may be nonsensory in nature and may require attention to be formed. Vowels are more or less steady-state sounds, whereas stop consonants involve rapid acoustic changes that may be too complex to be maintained in a long form of sensory memory.

In sum, it seems apt to say that sensory memory is a special type of memory that may not require attention to be formed. It cannot hold all aspects of the environment; perhaps it comprises a snapshot of information or slice of time and is unable to hold much information that changes over time. Nevertheless, it is sufficient to save information about far more than one can attentively process at once and thereby serves as a sort of multichannel bulletin board helping the perceiver to shift attention from one sensory channel to another as the incoming information warrants.

## 2.03.3 Why Study Sensory Memory?

Cognitive psychologists and other students of human behavior have not been consistently enthralled by the concept of sensory memory. The majority of them are interested in learning how meaningful information is processed, and for that enterprise, the fate of sensory information seems to be of secondary interest. Taking this paucity of interest further, Haber (1983) asserted that sensory memory is a byproduct of processing that is not really of any use in ecologically relevant circumstances, with rare exceptions such as when one wants to read on a dark, rainy night by the light produced by flashes of lightning. However, there are several key reasons why sensory memory is of interest. Some important phenomena in the modern world make use of visual sensory memory; without its smearing of the effects of sensation, we would not perceive motion pictures as moving but, rather, as a rapid succession of still frames. It seems likely, as well, that there are analogous phenomena in the natural world. As one spots a deer running across the forest, the continual disappearance of parts of the animal behind trees and reappearance of those parts is reconstructed by one's perceptual system to form a continuous event, the deer running. Sensory memory may be critical in allowing this smooth percept to be formed. In audition, the case is straightforward, inasmuch as sounds inherently change over time. Some mental device must capture segments of the sounds in order to interpret them. For example, as we already have noted, language learning may depend on sensory memory for how words are pronounced. Some less obvious reasons to be interested in sensory memory are as follows.

### 2.03.3.1 Understanding Qualia and Consciousness

Philosophers speak of qualia, the essential mental states corresponding to experiences. These may be considered the building blocks of conscious experience. The equivalent notion within psychology is the study of subjective experience that can be traced back to the introspectionist method of Wilhelm Wundt, who founded the first laboratory of experimental psychology in 1879. Experimental methods related to introspection make use of similarities in the verbal descriptions of an event across individuals. Descriptions of fleeting events get at the smallest temporal unit of consciousness, or psychological moment, during which all events appear simultaneous even if they are not (e.g., Stroud, 1955; Lichtenstein, 1961; Allport, 1968; Eriksen and Collins, 1968; Creel et al., 1970; Robinson and Pollack, 1971). In the typical experiment to examine this concept, multiple visual displays (such as two sets of dots) are presented rapidly, and when they are presented in close enough temporal proximity, they are perceived as a single image that includes all of the presented items (e.g., all of the dots together). The presentation time within which there is perceived simultaneity depends on stimulus factors but is typically in the range of 100 to 200 ms. One account of the psychological moment states that the sensory memory of the first presentation still must be sufficiently active when the second presentation arrives, so that it becomes impossible to tell the difference between sensory memory and sensation, allowing them to be fused into an apparently simultaneous percept. On that basis one can explain, for example, why a loud noise and a closely following quieter noise can be perceptually fused into a single noise if the gap between them is no more than 100 ms or so (Plomp, 1964). The second noise must be mistaken for part of the decaying sensory trace of the first noise, and the chances of that happening increase as the gap between them gets shorter and the second noise gets quieter.

There were two competing hypotheses of the psychological moment, and only one of them is consistent with a sensory memory account. According to a continuous-moment hypothesis, the psychological moment is a sliding window of time. This is compatible with the notion that the sensory memory of each stimulus can be combined with immediately successive stimuli. In contrast, according to a discrete-moment hypothesis, there are successive windows defined by internal neural events (e.g., oscillation in the firing of neurons so as to collect incoming sensory signals). Two brief events occurring, say, 80 ms apart would fall in either the same psychological moment or in different moments, depending on when they happened to occur relative to the boundary between successive moments.

Allport (1968) carried out an experiment to decide between these hypotheses that seems especially elegant and decisive. On every trial, 12 horizontal lines were presented in rapid succession, over and over, progressing from a line high on the oscilloscope screen to lines lower and lower on the screen. Only one line was presented at a given time, but because of perceived simultaneity, multiple lines were visible at once. The rate of succession was adjusted for each subject until exactly 11 of the 12 lines were visible at once. At this rate, one could observe what was termed shadow movement as the remaining line that could not be seen changed over time. Now, according to a continuous-moment hypothesis, the shadow should move from top to bottom. While the 12th, lowest line is presented, the sensory afterimage of the 1st, highest line is the oldest and fades. While this line 1 is again presented, the sensory afterimage of line 2 becomes the oldest and fades; while line 2 is again presented, the sensory afterimage of line 3 becomes the oldest and fades; and so on. In contrast, according to a discrete moment hypothesis, the shadow should move from bottom to top. If lines 1–11 fit within one discrete perceptual moment, line 12 is not visible. Then line 12, along with the next presentation of lines 1–10, will all fit into the next moment, and line 11 will not be visible; then lines 11–12 along with the next presentation of lines 1–9 will all fit into the next moment, and line 10 will not be visible; and so on. The results consistently showed downward shadow movement, supporting a continuous psychological moment and a sensory memory explanation.

### 2.03.3.2 Understanding Group Differences in Information Processing

If the psychological moment is determined by sensory memory, then group differences in sensory memory have important implications for how the groups perceive the world. It determines which events will be grouped together within the duration of sensory memory and which will be separated, beyond that duration (e.g., Dixon and DiLollo, 1994; Loftus and Irwin, 1998).

A study by Cowan et al. (1982) suggested that 8- to 9-week-old infants have a longer first phase of sensory memory than adults do. The procedure that was used was one of auditory backward recognition masking (Massaro, 1975b). In that type of procedure in adults, two brief sounds are presented in rapid succession, and the subject is to identify the first sound in a multiple-choice test. Performance improves as the time between the onsets of the first and second sounds (the stimulus onset asynchrony or SOA) increases to about 250 ms. Even if the choices are so close that performance is substantially below 100%, performance levels off to an asymptotic level at about that SOA. The explanation (in concert with other, convergent procedures that we discuss later) is that information must be extracted over time from sensory memory into a more abstract form of memory until the second sound masks or overwrites the sensory memory of the first sound, interrupting the process of extracting information. By an SOA of 250 ms, the auditory sensory memory fades, so delays of the second, masking stimulus beyond that point would not help. For infant study, an *ah-ah* vowel pair was presented repeatedly, but with different SOAs among the pairs. Sometimes, an *eh-ah* pair was presented instead, but the access to this different pair was restricted to pairs with a particular SOA. The dependent measure of sound discrimination was how long and how vigorously infants were willing to suck on a pacifier that yielded not food but access to pairs that changed from *ah-ah* to *eh-ah,* rather than being stuck with a monotonous repetition of *ah-ah*. (For other infants, the assignment of the two vowels was reversed.) Higher sucking rates for this condition than for a condition in which there was no acoustic benefit of sucking yielded evidence of sound discrimination when the changes occurred within pairs with a 400-ms SOA, but not when the changes occurred within pairs with the 250-ms SOA that is sufficient for optimal performance in adult studies.

Various methods also have been used to show that the duration of sensory memory may differ from the norm in children with mental retardation (Campbell, and Meyer, 1981) or reading disability (Sipe and Engle, 1986) and in patients who have had unilateral temporal lobectomy (Efron et al., 1985). It is not known whether sensory memory abnormality contributes to cognitive disabilities in these groups.

### 2.03.3.3 Eliminating Contamination from Nonsensory Aspects of Cognition

Even if one is interested in abstract forms of memory, it is necessary to examine sensory memory in order to control its contribution in various test procedures. A good example is the procedure of Luck and Vogel (1997) to examine working memory. An array of simple, schematic objects is presented and then followed by a second array identical to the first or differing in the identity of one of the objects. In such procedures, people can remember about four items (cf. Sperling, 1960). If the interest is on that working memory limit, then one needs to be sure that sensory memory has faded away before the test. One could use a partial-report cue to determine when it has faded, as Sperling did. Another method is to mask the array with another, interfering array after various intervals and to determine how much information already has been transferred from sensory memory to working memory. Woodman and Vogel (2005) did that and suggested that sensory memory for items in an array was transferred to working memory at a rate of about 50 ms per item in the array.

A similar point could be made with respect to understanding attention. Imagine an experiment in which different word lists are presented simultaneously to the left and right ears. Suppose one has evidence suggesting that an individual can attend to both channels of speech at once. Such evidence may be misleading. If the speech is presented too slowly, there is the possibility of instead (1) attending to the word presented to one ear, and then (2) switching attention to the other ear in time to perceive the sensory memory of the word presented to that ear. If this is the case, speeding up the presentation may eliminate evidence that both channels are being perceived. For an example of this see Wood et al. (1997). In attention research, as in working memory research, the effect of sensory memory must be taken into account.

## 2.03.4 Techniques to Examine Sensory Memory

Of necessity, we already have discussed a number of techniques used to examine sensory memory. Now it should be helpful to take a brief inventory of these methods. In taking this inventory it is important to keep in mind that different methods disagree. Still, it may be proposed that different outcomes theoretically might result from a common sensory memory. For example, a subjective impression of the duration of a stimulus might result from the duration for which the sensory neural response exceeds a certain intensity, whereas a measure of information about the stimulus might result from an integration of the neural response intensity over time (cf. Cowan, 1987; Loftus and Irwin, 1998).

### 2.03.4.1 Sensory Persistence Procedures

In the most straightforward types of investigation, stimuli extended over time are perceived as being simultaneous, as in the investigations of the psychological moment described above. Johann Andreas Segner, a German physicist and mathematician living in the 1700s, attached a glowing coal to a cartwheel, rotating the wheel at various speeds. He found that a complete circle was perceived if the wheel was rotated at a rate of at least 100 ms per rotation. This implies that the sensory memory of the glowing coal fell below some minimal level of brightness by about 100 ms.

Efron (1970a,b,c) carried out quite a nice set of experiments to refine the sensory persistence procedure. An indicator (e.g., a click) stimulus was presented along with a target stimulus (e.g., a light flash), and the study estimated when the indicator sounded as if it occurred at the same time as the offset of the target (or, in a control condition, the onset of the target). The result was that the onset of the target was only very slightly overestimated, whereas the offset was overestimated by up to about 200 ms. The nature of the overestimation depended heavily on the duration of the target, such that the target appeared to have a minimal perceived duration of about 200 ms. Very similar results were obtained when the target was visual and when it was auditory. The duration of a perception appears to be the duration of the perceptual response, and if the target stimulus is brief, it reflects the duration of the target plus its perceptual afterimage or sensory memory.

### 2.03.4.2 Partial-Report Procedures

We already have described the procedures like that of Sperling (1960) and Darwin et al. (1972), in which an array of items is followed by a partial-report cue that allows part of the sensory memory representation to be transferred to a more abstract, categorized, reportable state, working memory. One enigma worthy of consideration is that, whereas persistence procedures have produced similar results for vision and audition, partial-report procedures seem to produce much shorter periods of cue utility for vision (under 1 s) than for audition (about 4 s). We return to this enigma when discussing theories of forgetting from sensory memory.

#### 2.03.4.3 Selective-Attention Procedures

We have touched upon procedures in which an auditory stimulus is ignored at the time of its presentation and only subsequently receives the benefit of attention applied to the sensory memory (Broadbent, 1958; Cowan et al., 1990; there are various other examples such as Treisman, 1964; Norman, 1969; Glucksberg and Cowen, 1970).

It is possible also to examine memory for unattended material in the visual modality. Various techniques can be used to get the subject to contract or expand the focus of visual attention (Eriksen and St. James, 1986; LaBerge and Brown, 1989), and one can then examine memory for information inside or outside of the attentional focus. One difficulty is that there is poorer perceptual analysis of information in the periphery of the visual field, regardless of whether that part of the field is the focus of attention. Usually, the center of the visual field of gaze is also the focus of attention, so attention and visual acuity are confounded. (That is not the case in audition, for which there is no change in the effectors accompanying attention.) Luckily, it is possible to direct a subject's attention to an area outside of the center of gaze (e.g., Brefczynski and DeYoe, 1999). For this reason, it is theoretically possible to determine the effects of attention on visual perception and examine memory for centrally presented but unattended stimuli. It does seem clear that visual attention affects perception, but more research is needed to reveal the details of unattended sensory images in the center of gaze.

#### 2.03.4.4 Backward-Masking Procedures

We already have touched upon the technique of backward masking, in which a brief target stimulus is followed by a mask and impedes recognition of the target. Notably, little masking occurs if the mask precedes the target (Massaro, 1973). This confirms that the critical aspect of backward masking is overwriting of the target's sensory memory by the mask, not the mere proximity of target and mask. It is also noteworthy that the period of backward masking obtained in the auditory modality is quite similar to the visual modality (Turvey, 1973). That appears to be true also in persistence procedures, but not in partial-report or selective-attention procedures, a point to which we return shortly.

One benefit of the masking procedure is that it can be used to show that the neural locus of sensory memory is not entirely peripheral. Turvey (1973) showed that substantial backward masking occurs even when the target was presented to one ear and the mask was presented to the other ear. (For convergent evidence of a central locus of the visual afterimage using a persistence technique, see Haber and Standing, 1969, 1970.) Kallman and Morris (1984) showed something similar in audition, though the opposite conclusion is often cited (Hawkins and Presson, 1977). Cowan (1995, Section 2.5) cited physiological studies supporting the notion that auditory sensory memory has a central locus.

## 2.03.5 Theories of Forgetting From Sensory Memory

### 2.03.5.1 Modality-Specific Rates of Decay

It is interesting to see how a scientific field responds to inconsistency. Although the methods described above have been present for quite some time, most theoretical mentions of sensory memory in textbooks seem to go along with the conclusion that auditory memory outlasts visual memory. That could account for the findings of partial-report and selective-attention procedures, but not the findings of persistence and backward-masking procedures. An alternative view is described in the sections that follow.

### 2.03.5.2 Two Phases of Sensory Memory with Different Rates of Decay

The study of Sperling (1960) was truly seminal in the field. When Darwin et al. (1972) found that sensory memory appeared to be useful for a much longer period in audition (about 4 s) than Sperling found in vision (less than 1 s), it led to the belief that auditory memory lasts longer than visual memory. However, Massaro (1976) offered a different interpretation. Whereas Sperling's experiments used a large number of simultaneous characters (e.g., 12), the smaller number of simultaneous characters used by Darwin et al. (1972) allowed perceptual analysis. According to this view, the sensory memory observed by Sperling was preperceptual, whereas that was not true of the memory observed in the auditory studies. Consistent with Massaro's view, Cowan (1984, 1988, 1995) summarized evidence from various procedures that there are two phases of sensory memory in both the visual and auditory modalities (as well as in other modalities): a short, literal phase lasting about 250 ms and a longer, second phase lasting several seconds. The second phase was said to comprise temporarily activated sensory features in long-term memory and was said to be both functionally similar to temporarily activated semantic features in long-term memory and much more processed than the first phase.

A couple of studies, one in vision and one in audition, provide striking evidence that there are two types of sensory memory. Phillips (1974) presented two spatial patterns of black and white squares that differed in at most the fill of one square. At short interpattern delays, performance was excellent but was harmed if there was a displacement of the screen location from the first pattern to the second. It was as if the subject actually could see the superimposition of the patterns. In contrast, at longer delays, performance was poorer, and displacement of the screen location did not matter. This suggests that the longer representation was more abstract than the shorter representation.

Kallman and Massaro (1979) carried out a backward-masking procedure in which a standard tone had to be compared to a subsequent comparison tone. Either the standard or the comparison tone was followed by a masking tone. At issue in this experiment was the effect of the similarity between the mask and the tone it masked. When the mask followed the standard tone, it could result in either interference with extraction of information from the sensory trace, which could be termed Masking Type 1, or overwriting of information about the tone even after it has been extracted from the sensory trace, which could be termed Masking Type 2. As the interval between the standard tone and the mask increased, Masking Type 1 presumably disappeared, whereas Masking Type 2 remained. On other trials, it was the comparison tone that was masked, and therefore, only Masking Type 1 was possible; a judgment could be made as soon as information was extracted from that comparison tone. Given that similarity effects were obtained only for Masking Type 2, it was possible to distinguish two phases of auditory memory with different properties. These were termed preperceptual auditory storage and synthesized auditory memory, respectively. These terms correspond to the short and long auditory stores of Cowan (1984).

### 2.03.5.3 No-Decay Theories

Last, it must be mentioned that some investigators have proposed that there are no decaying memories, including no decaying sensory memory. These investigators view the decline in performance with increasing retention intervals as a matter of a loss of temporal distinctiveness of the items at the end of the list (Neath and Crowder, 1990; Crowder, 1993; Nairne, 2002). That type of theory, combined with the notion that there is better temporal distinctiveness in the auditory modality (e.g., Glenberg and Swanson, 1986), could help to explain why there is an advantage for items at the end of a verbal list presented in the auditory as opposed to the visual modality (cf. Penney, 1989; Marks and Crowder, 1997; Beaman and Morton, 2000; Cowan et al., 2004). However, it is not an easy matter to distinguish between decay and distinctiveness accounts.

Cowan et al. (1997) considered that there might be a distinctiveness explanation for performance in two-tone comparison procedures, in which performance decreases as a function of the time between the standard and comparison tones. As that time increases, it may become larger than the time between trials, so that the tones are not neatly grouped in episodic memory into the trials to which they belong. To overcome this problem Cowan et al. manipulated the time between trials as well as the time between the standard and comparison tones within a trial. Examining trials with the ratio between these two times held constant, and performance decreased only slightly as the time between the standard and comparison tone increased, until it exceeded 6 s. Between 6 and 12 s, the drop was a bit more severe. However, Cowan et al. (2001) reexamined the evidence, taking into account distinctiveness caused by intervals before the penultimate trial, and found no strong evidence of decay (although the data were preliminary in this regard).

A remaining possibility is that, in these procedures, sensory memory information that is attended can be rehearsed (Keller et al., 1995). A study that argues against the effects of time on nonsensory short-term memory (Lewandowsky et al., 2004) takes into account verbal rehearsal, but not the possibility of an attention-based, possibly nonverbal type of rehearsal (cf. Barrouillet et al., 2004). It remains to be seen whether sensory information that is unattended at the time that it is presented, and thus cannot be rehearsed, is lost over time in a way that can be explained by temporal distinctiveness or in a way that cannot be so explained.

## 2.03.6 Comments on the Future of Research on Sensory Memory

Sensory memory is one of the oldest topics in experimental psychology. Currently, there is only a small to moderate amount of ongoing research on the topic, but that does not imply that the great problems in the field have been solved, or that the field has become trivial or uninteresting. Sensory memory is an intrinsically fascinating set of neural mechanisms that must be strongly associated with basic conscious experience. As brain researchers investigate how humans know what is real and what is only imaginary, their research no doubt will lead them back to the persistent mysteries within the topic of sensory memory.

## References


Alain C, Arnott SR, Hevenor S, Graham S, and Grady CL (2001) ''What'' and ''Where'' in the human auditory system. *Proc. Natl. Acad. Sci. USA* 98: 12301–12306.

Allport DA (1968) Phenomenal simultaneity and the perceptual moment hypothesis. *Br. J. Psychol.* 59: 395–406.

Barrouillet P, Bernardin S, and Camos V (2004) Time constraints and resource sharing in adults' working memory spans. *J. Exp. Psychol. Gen.* 133: 83–100.

Bartleson CJ (1960) Memory colors of familiar objects. *J. Opt. Soc. Am.* 50: 73–77.

Beaman CP and Morton J (2000) The separate but related origins of the recency effect and the modality effect in free recall. *Cognition* 77: B59–B65.

Brefczynski JA and DeYoe EA (1999) A physiological correlate of the 'spotlight' of visual attention. *Nat. Neurosci.* 2: 370–374.

Broadbent DE (1958) *Perception and Communication*. London: Pergamon Press.

Campbell EM and Meyer PA (1981) Evaluation of auditory sensory memory of mentally retarded and nonretarded persons. *Am. J. Ment. Defic.* 86: 50–59.

Cowan N (1984) On short and long auditory stores. *Psychol. Bull.* 96: 341–370.

Cowan N (1987) Auditory sensory storage in relation to the growth of sensation and acoustic information extraction. *J. Exp. Psychol. Hum. Percept. Perform.* 13: 204–215.

Cowan N (1988) Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system. *Psychol. Bull.* 104: 163–191.

Cowan N (1995) *Attention and Memory: An Integrated Framework*. Oxford Psychology Series, No. 26.New York: Oxford University Press.

Cowan N, Lichty W, and Grove TR (1990) Properties of memory for unattended spoken syllables. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 258–269.

Cowan N, Saults JS, and Brown GDA (2004) On the auditory modality superiority effect in serial recall: Separating input and output factors. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 639–644.

Cowan N, Saults JS, and Nugent LD (1997) The role of absolute and relative amounts of time in forgetting within immediate memory: The case of tone pitch comparisons. *Psychon. Bull. Rev.* 4: 393–397.

Cowan N, Saults JS, and Nugent L (2001) The ravages of absolute and relative amounts of time on memory. In: Roediger HL, III, Nairne JS, Neath I, and Surprenant A (eds.) *The Nature of Remembering: Essays in Honor of Robert G. Crowder*, pp. 315–330. Washington DC: American Psychological Association.

Cowan N, Suomi K, and Morse PA (1982) Echoic storage in infant perception. *Child Dev.* 53: 984–990.

Creel W, Boomsliter PC, and Powers SR, Jr. (1970) Sensations of tones as perceptual forms. *Psychol. Rev.* 77: 534–545.

Crowder RG (1993) Short-term memory: Where do we stand? *Memory and Cognition,* 21: 142–145.

Darwin CJ, Turvey MT, and Crowder RG (1972) An auditory analogue of the Sperling partial report procedure: Evidence for brief auditory storage. *Cognit. Psychol.* 3: 255–267.

Dixon P and Di Lollo V (1994) Beyond visible persistence: An alternative account of temporal integration and segregation in visual processing. *Cognit. Psychol.* 26: 33–63.

Efron R (1970a) The relationship between the duration of a stimulus and the duration of a perception. *Neuropsychologia* 8: 37–55.

Efron R (1970b) The minimum duration of a perception. *Neuropsychologia* 8: 57–63.

Efron R (1970c) Effects of stimulus duration on perceptual onset and offset latencies. *Percep. Psychophys.* 8: 231–234.

Efron R, Yund EW, Nichols D, and Crandall PH (1985) An ear asymmetry for gap detection following anterior temporal lobectomy. *Neuropsychologia* 23: 43–50.

Eriksen CW and Collins JF (1968) Sensory traces versus the psychological moment in the temporal organization of form. *J. Exp. Psychol.* 77: 376–382.

Eriksen CW and St. James JD (1986) Visual attention within and around the field of focal attention: A zoom lens model. *Percep. Psychophys.* 40: 225–240.

Glenberg AM and Swanson NC (1986) A temporal distinctiveness theory of recency and modality effects. *J. Exp. Psychol. Learn. Mem. Cogn.* 12: 3–15.

Glucksberg S and Cowen GN, Jr. (1970) Memory for nonattended auditory material. *Cognit. Psychol.* 1: 149–156.

Haber RN (1983) The impending demise of the icon: A critique of the concept of iconic storage in visual information processing. *Behav. Brain Sci.* 6: 1–54.

Haber RN and Standing LG (1969) Direct measures of short-term visual storage. *Q. J. Exp. Psychol.* 21: 43–54.

Haber RN and Standing LG (1970) Direct estimates of the apparent duration of a flash. *Can. J. Psychol.* 24: 216–229.

Hawkins HL and Presson JC (1977) Masking and preperceptual selectivity in auditory recognition. In: Dornic S (ed.) *Attention and Performance VI*, pp. 195–212. Hillsdale, NJ: Erlbaum.

Haxby JV, Grady CL, Horwitz B, et al. (1991) Dissociation of object and spatial visual processing pathways in human extrastriate cortex. *Proc. Natl. Acad. Sci. USA* 88: 1621–1625.

Irwin DE and Yeomans JM (1986) Sensory registration and informational persistence. *J. Exp. Psychol. Hum. Percept. Perform.* 12: 343–360.

Jarvella,RJ (1970) Effects of syntax on running memory span for connected discourse. *Psychon. Sci.* 19: 235–236.

Kallman HJ and Massaro DW (1979) Similarity effects in backward recognition masking. *J. Exp. Psychol. Hum. Percept. Perform.* 5: 110–128.

Kallman HJ and Morris ME (1984) Backward recognition masking as a function of ear of mask presentation. *Percep. Psychophys.* 35: 379–384.

Keller TA, Cowan N, and Saults JS (1995) Can auditory memory for tone pitch be rehearsed? *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 635–645.

Kolers PA (1974) Two kinds of recognition. *Can. J. Psychol.* 28: 51–61.

LaBerge D and Brown V (1989) Theory of attentional operations in shape identifications. *Psychol. Rev.* 96: 101–124.

Lewandowsky S, Duncan M, and Brown GDA (2004) Time does not cause forgetting in short-term serial recall. *Psychon. Bull. Rev.* 11: 771–790.

Lichtenstein M (1961) Phenomenal simultaneity with irregular timing components of the visual stimulus. *Percept. Motor Skills* 12: 47–60.

Loftus GR and Irwin DE (1998) On the relations among different measures of visible and informational persistence. *Cognit. Psychol.* 35: 135–199.

Luck SJ and Vogel EK (1997) The capacity of visual working memory for features and conjunctions. *Nature* 390: 279–281.

Marks A and Crowder RG (1997) Temporal distinctiveness and modality. *J. Exp. Psychol. Learn. Mem. Cogn.* 23: 164–180.

Massaro DW (1973) A comparison of forward versus backward recognition masking. *J. Exp. Psychol.* 100: 434–436.

Massaro DW (1975a) *Experimental Psychology and Information Processing*. Chicago: Rand McNally.

Massaro DW (1975b) Backward recognition masking. *J. Acoust. Soc. Am.* 58: 1059–1065.

Massaro DW (1976) Perceptual processing in dichotic listening. *J. Exp. Psychol. Hum. Learn. Mem.* 2: 331–339.

Massaro DW and Loftus GR (1996) Sensory and perceptual storage: Data and theory. In: Bjork EL and Bjork RA (eds.) *Memory*, pp. 67–99. San Diego: Academic Press.

Mewhort DJK, Campbell AJ, Marchetti FM, and Campbell JID (1981) Identification, localization, and ''iconic memory'': An evaluation of the bar-probe task. *Mem. Cogn.* 9: 50–67.

Nairne JS (2002) Remembering over the short-term: The case against the standard model. *Annu. Rev. Psychol.* 53: 53–81.

Neath I and Crowder RG (1990) Schedules of presentation and temporal distinctiveness in human memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 316–327.

Norman DA (1969) Memory while shadowing. *Q. J. Exp. Psychol.* 21: 85–93.

Penney CG (1989) Modality effects and the structure of short-term verbal memory. *Mem. Cogn.* 17: 398–422.

Phillips WA (1974) On the distinction between sensory storage and short-term visual memory. *Percep. Psychophys.* 16: 283–290.

Pisoni DB (1973) Auditory and phonetic memory codes in the discrimination of consonants and vowels. *Percep. Psychophys.* 13: 253–260.

Plomp R (1964) Rate of decay of auditory sensation. *J. Acoust. Soc. Am.* 36: 277–282.

Pons TP, Garraghty PE, and Mishkin M (1992) Serial and parallel processing of tactual information in somatosensory cortex of rhesus monkeys. *J. Neurophysiol.* 68: 518–527.

Ratner C and McCarthy J (1990) Ecologically relevant stimuli and color memory. *J. Gen. Psychol.* 117: 369–377.

Robinson CE and Pollack I (1971) Forward and backward masking: Testing a discrete perceptual-moment hypothesis in audition. *J. Acoust. Soc. Am.* 50: 1512–1519.

Rostron AB (1974) Brief auditory storage: Some further observations. *Acta Psychol.* 38: 471–482.

Sachs JS (1967) Recognition memory for syntactic and semantic aspects of connected discourse. *Percep. Psychophys.* 2: 437–442.

Sipe S and Engle RW (1986) Echoic memory processes in good and poor readers. *J. Exp. Psychol. Learn. Mem. Cogn.* 12: 402–412.

Sperling G (1960) The information available in brief visual presentations. *Psychol. Monogr. 74* (Whole No. 498.) (Whole No. 498.)

Stroud JM (1955) The fine structure of psychological time. In: Quastler H (ed.) *Information Theory in Psychology*, pp. 174–207. Glencoe, IL: Free Press.

Townsend VM (1973) Loss of spatial and identity information following a tachistoscopic exposure. *J. Exp. Psychol.* 98: 113–118.

Treisman AM (1964) Selective attention in man. *Br. Med. Bull.* 20: 12–16.

Treisman AM and Gelade G (1980) A feature integration theory of attention. *Cognit. Psychol.* 12: 97–136.

Treisman M and Rostron AB (1972) Brief auditory storage: A modification of Sperling's paradigm. *Acta Psychol.* 36: 161–170.

Turvey MT (1973) On peripheral and central processes in vision: Inferences from an information processing analysis of masking with patterned stimuli. *Psychol. Rev.* 80: 1–52.

Weichselgartner E and Sperling G (1985) Continuous measurement of visible persistence. *J. Exp. Psychol. Hum. Percept. Perform.* 11: 711–725.

Weldon MS, Roediger HL, Beitel DA, and Johnston TR (1995) Perceptual and conceptual processes in implicit and explicit tests with picture fragment and word fragment cues. *J. Mem. Lang.* 34: 268–285.

Wood NL, Stadler MA, and Cowan N (1997) Is there implicit memory without attention? A re-examination of task demands in Eich's (1984) procedure. *Mem. Cogn.* 25: 772–779.

Woodman GF and Vogel EK (2005) Fractionating working memory: Consolidation and maintenance are independent processes. *Psychol. Sci.* 16: 106–113.

# 2.04 Working Memory

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## 2.04.1 Introduction

A common feature of our everyday mental life is the need to hold information in mind for brief periods of time. We frequently have to remember a new telephone or vehicle registration number, to write down the spelling of an unusual name that has been dictated to us, or to follow spoken instructions to find our destination in an unfamiliar environment. At other times, we need to engage in mental activities that require both temporary storage and demanding cognitive processing. Mental arithmetic provides a good example of this: successfully multiplying two numbers such as 43 and 27 in our heads involves storing not only the numbers but the products of the intermediate calculations, accessing and applying the stored rules of multiplication and addition, and integrating the various pieces of information to arrive at the correct solution. Our conscious experience of the calculation attempt is of a kind of mental juggling, in which we try to keep all elements of the task – the numbers we are trying to remember as well as the calculations – going at the same time. Often, the juggling attempt will fail, either because the capacity of working memory is exceeded, or because we become distracted and our attention is diverted away from the task in hand.

Working memory – which is the term widely used by psychologists to refer to the set of cognitive processes involved in the temporary storage and manipulation of information – supports all of these activities and many more. A useful informal way of conceptualizing working memory is as a mental jotting pad that we can use to record useful material for brief periods of time, as the need arises in the course of our everyday cognitive activities. Although it a valuable and highly flexible resource, working memory has several limitations: its storage capacity is limited, and it is a fragile system whose contents are easily disrupted. Once lost from working memory, material cannot be recovered.

The basic features of working memory are described in this chapter. Leading theoretical accounts of the cognitive processes involved in working memory are described, and key findings and experimental phenomena are outlined. As it is now also known that working memory is important not only for the temporary retention of information, but also for the acquisition of more permanent knowledge, theories of how different aspects of working memory mediate learning are also considered in this chapter.

## 2.04.2 The Working Memory Model

One influential theoretical account of working memory has framed much of the research and thinking in this field for several decades. In 1974, Baddeley and Hitch advanced a model of working memory that has been substantially refined and extended over the intervening period. The influence of the working memory model extends far beyond the detailed structure of its cognitive processes, which are considered in the following sections. The radical claim made by Baddeley and Hitch was that working memory is a flexible multicomponent system that satisfies a wide range of everyday cognitive needs for temporary mental storage – in other words, it does important work for the user. The distinction between short-term memory and working memory is a key element in the philosophy of this approach. The term working memory refers to the whole set of cognitive processes that comprise the model, which as we will see includes higher-level attentional and executive processes as well as storage systems specialized for particular information domains. Activities that tap a broad range of the functions of working memory, including both storage and higher-level control functions, are often described as working memory tasks. The term short-term memory, on the other hand, is largely reserved for memory tasks that principally require the temporary storage of information only. In this respect, short-term memory tasks tap only a subset of working memory processes. Detailed examples of each of these classes of memory task are provided in later sections.

A further key element of the Baddeley and Hitch (1974) approach is its use of dual-task methodology to investigate the modular structure of the working memory system. These researchers have developed a set of laboratory techniques for occupying particular components of the working memory system, which can then be used to investigate the extent to which particular activities engage one or another component. By the logic of dual-task methodology, any two activities that are unimpaired when conducted in combination do not tap common limited capacity systems. In contrast, performance decrements when two tasks are combined indicate that they share a reliance on the same component. This empirical approach has proved invaluable in fractionating working memory into its constituent parts, leading to the most recent version of the working memory model, advanced by Baddeley in 2000 (Baddeley, 2000) (**Figure 1**).

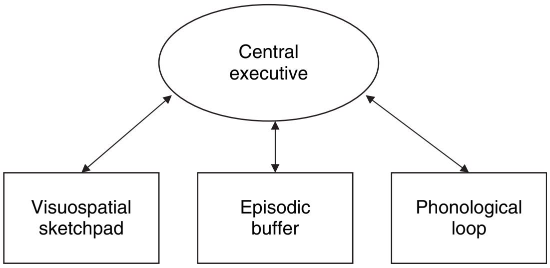


**Figure 1** The Baddeley (2000) working memory model.

This model consists of four components. Two of these components, the phonological loop and the visuospatial sketchpad, are slave systems that are specialized for the temporary storage of material in particular domains (verbal and visuospatial, respectively). The central executive is a higher-level regulatory system, and the episodic buffer integrates and binds representations from different parts of the system. The nature of each of these components and associated empirical evidence are described in the following sections. Note also that components of working memory are directly linked with longer-term memory systems in various informational domains. The nature of the interface between working memory and the acquisition of knowledge is considered in later sections of the chapter.

### 2.04.2.1 The Phonological Loop

Originally termed the articulatory loop by Baddeley and Hitch (1974), the phonological loop is a slave system dedicated to the temporary storage of material in terms of its constituent sounds, or phonemes. The two-component model of the phonological loop advanced by Baddeley in 1986 is shown in **Figure 2**. Representations in the phonological short-term store are subject to rapid time-based decay. Auditory speech information gains obligatory access to the phonological store.

Subvocal rehearsal reactivates serially the contents of the short-term store, in a process that corresponds closely to overt articulation (speaking), but which does

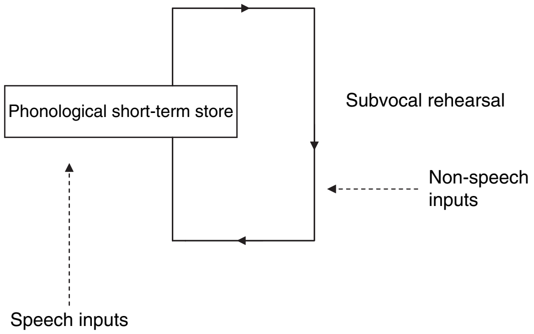


**Figure 2** The phonological loop model, based on Baddeley (1986).

not necessarily involve the movement of the speech apparatus or the generation of speech sounds. Representations in the phonological store that are rehearsed before they have time to decay can be maintained in the phonological loop indefinitely, provided that rehearsal continues. Rehearsal consists of the high-level activation of speech-motor planning processes (Bishop and Robson, 1989; Caplan et al., 1992) and is a time-limited process in which lengthier items take longer to activate than short items. Material that is not presented in the form of spoken language but which is nonetheless associated with verbal labels, such as printed words or pictures of familiar objects, can enter the phonological store via rehearsal, which generates the corresponding phonological representations from stored lexical knowledge.

#### *2.04.2.1.1 Empirical phenomena*

This fractionated structure to the phonological loop is consistent with a wide range of experimental phenomena from the serial recall paradigm, in which lists of items are presented serially for immediate recall in the original input sequence. Evidence that verbal material is held in a phonological code is provided by the fact that irrespective of whether the memory lists are presented in auditory form or in the form of print, recall is poorer for sequences in which the items share a high degree of phonological similarity (e.g., C, G, B, V, T) than for those which have little overlap in phonological structure (e.g., X, H, K, W, Q). This effect of phonological similarity, first reported by Conrad (1964) and replicated many times subsequently, indicates that serial recall is mediated by phonological representations. Degradation of these representations, possibly due to decay, will thus cause confusion between representations of items with highly similar phonological structures.

The obligatory access of auditory speech information to the phonological loop is demonstrated by the irrelevant speech effect. Serial recall of visually presented verbal items is impaired if spoken items are presented during list presentation, even though participants are told to ignore these stimuli. Moreover, the recall advantage to phonologically distinct over phonologically similar sequences is eliminated under such conditions of irrelevant speech (Colle and Welsh, 1976; Suprenant et al., 1999). This finding indicates that irrelevant speech operates on the same process that gives rise to the phonological similarity effect, so that the unwanted stimuli generate representations in the phonological store that disrupt those of the list items to be recalled.

Evidence for the existence of a distinct subvocal rehearsal process that operates on the contents of the phonological store is provided by other empirical phenomena. An important finding first reported by Baddeley et al. (1975) is that serial recall accuracy is impaired when memory lists contain lengthy items (e.g., aluminum, hippopotamus, tuberculosis) than otherwise matched short items (e.g., zinc, stoat, mumps). Detailed analyses have established that a linear function related recall accuracy to the rate at which participants can articulate the memory sequence: items that are be spoken more rapidly are recalled more accurately, to a commensurate degree. This phenomenon, known as the word length effect, is present for visually and auditorily presented verbal material and is suggested to reflect the serial rehearsal process, which requires more time to re-activate lengthy than short items. As a consequence, representations in the phonological store of lengthy items are more likely to have decayed between successive rehearsals, leading to decay and loss of information.

Support for this interpretation is provided by findings that the word length effect disappears if participants engage in articulatory suppression by saying something irrelevant such as "hiya, hiya, hiya" during presentation of the memory list, for both visually and auditorily presented lists (Baddeley et al., 1975, 1984). These results can be simply explained. Having to engage in irrelevant articulation during a memory task prevents effective rehearsal of the memory items themselves – it simply is not possible to say one thing and to rehearse subvocally something else. As rehearsal is prevented in this condition, there can be no further impairment of recall with lengthy as opposed to short memory items, as this effect is also tied to the rehearsal process.

It should be noted that because visually presented material requires rehearsal to access the phonological store, preventing rehearsal via articulatory suppression should also eliminate the phonological similarity effect with visual presentation, as the material will not reach the store for the similarity-based interference to occur. This prediction has been supported by findings from many studies (Murray, 1968; Peterson and Johnson, 1971).

The claim that the word length effect arises only from subvocal rehearsal has not gone uncontested. Lengthier items are slower not only to rehearse but also to recall, and there is convincing evidence that the increased delay in recalling longer items is one cause of lower performance, probably due to the increased opportunity for time-based decay of the phonological representations. Cowan et al. (1992) employed mixed lists composed of both short and long words to investigate the effects of recall delay. They found a linear relation between the amount of time elapsing from the beginning of the recall attempt and the accuracy of recall, with recall declining as the delay increased (see also, Cowan et al., 1994). One possibility is that the word length effect is multiply determined, and that the slower rate of rehearsal for long than short items is just one of several mechanisms causing lower levels of recall accuracy for lists composed of lengthy stimuli.

Debate concerning the detailed processes underpinning experimental phenomena such as the effects of word length and irrelevant speech (e.g., Neath et al., 2003; Jones et al., 2006) continues, and will in time result in a fuller understanding of the precise mechanisms of serial recall. More generally, though, the broad distinction between the short-term store and rehearsal subcomponents of the phonological loop has received substantial support from several different empirical traditions. It is entirely consistent with evidence of developmental fractionation of the subcomponents of the phonological loop during the childhood years (see Gathercole and Hitch, 1993; Palmer, 2000, for reviews). The phonological store appears to be in place by the preschool period: by roughly 4 years of age, children show adult-like sensitivity to the phonological similarity of the lists items for auditorily presented material (Hitch and Halliday, 1983; Hulme and Tordoff, 1989). The subvocal rehearsal strategy, in contrast, emerges at a later time, typically after 7 years of age. Flavell et al. (1967) observed many years ago that very young children do not show the overt signs of rehearsal, such as lip movements and overt repetition, that characterize older children. Children below 7 years of age are also not disrupted by recalling memory sequences composed of lengthy rather than short items (Hitch and Halliday, 1983), although word length effects do emerge in children as young as 5 years of age if they are trained in the use of rehearsal strategies (Johnson et al., 1987). Also, there is also no consistent association between the articulatory rate and memory span in 5-year-old children, although strong links are found in adults (Gathercole et al., 1994a). Together, these findings indicate that although the phonological store is present at a very early point in children, the use of subvocal rehearsal as a means of maintaining the rapidly decaying representations in the store emerges only during the middle childhood years.

The phonological store and rehearsal process also appear to be served by distinct neuroanatomical regions of the left hemisphere of the brain. Evidence from patients with acquired brain damage resulting in impairments of verbal short-term memory indicates that short-term phonological storage is associated with the inferior parietal lobule of the left hemisphere, whereas rehearsal is mediated by Broca's area, in the left premotor frontal region (see Vallar and Papagno, 2003; Muller and Knight, 2006, for reviews). Findings from neuroimaging studies using methods such as positron emission tomography and functional magnetic resonance imaging to identify the areas of the brain activated by verbal short-term memory tasks in typical adult participants have further reinforced the neuroanatomical distinction between the phonological store and rehearsal (see Henson, 2005, for review).

#### 2.04.2.1.2 A computational model of the phonological loop

Despite its simplicity, the Baddeley (1986) model of the phonological loop is capable of explaining much of the evidence outlined in the preceding section and several other experimental phenomena. It does, however, have one notable shortcoming as a model of serial recall. Although this paradigm requires the accurate retention of both the items in the memory list and their precise sequence, the model focuses exclusively on the representation of item information and therefore fails to account for how the serial order of list items is retained in the phonological loop. As a consequence, it cannot accommodate many detailed aspects of serial recall behaviour. One important characteristic of serial recall is the serial position function, the asymmetric bow-shaped curve that arises from high levels of accuracy of recalling initial list items (the primacy effect), relatively poor recall of mid-list items, and a moderate increase in accuracy for items at the end of the sequence (the recency effect). Another key finding is that the most common category of errors in serial recall is order errors, in which items from the original position migrate to nearby but incorrect positions in the output sequence (Bjork and Healy, 1974; Henson et al., 1996). The Baddeley (1986) model of the phonological loop provides no explanation of either of these features of verbal short-term memory.

Burgess and Hitch (1992) addressed this problem by developing and implementing a connectionist network model that incorporated a mechanism for retaining the serial order of items in addition to temporary phonological representations and an analog of rehearsal that corresponds to the phonological loop. The structure of the model is shown in **Figure 3**. It consists of four separate layers of nodes that represent input phonemes, words, output phonemes, and a context signal. Serial order is encoded by associating the activated item representation with a slowly evolving context signal containing a subset of active nodes that change progressively during presentation of the list, and can be conceptualized as a moving window representing time such that successive context states are more similar to one another than temporally distant states. Presentation of an item causes temporary activation of input phoneme nodes, word nodes, and output phoneme nodes via existing interconnections. When one item node succeeds in becoming the most active, a temporary association is formed between the winning item node

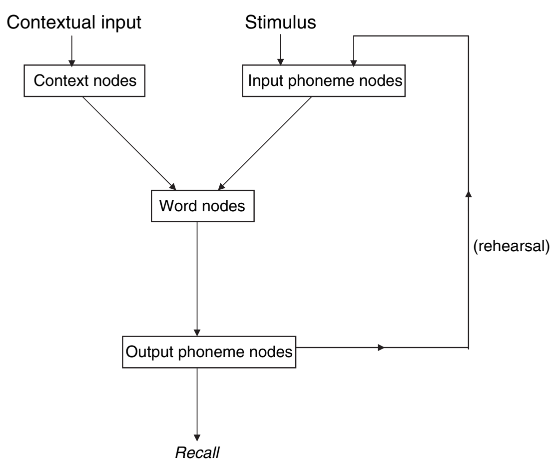


**Figure 3** Simplified architecture of the Burgess and Hitch (1992) network model of the phonological loop.

and currently active context nodes. The item node is then suppressed, allowing the same process to be repeated for the next item in the sequence. In this model, rehearsal consists of feedback from the output phonemes (activated following selection of the winning item node) to the input phonemes.

At recall, the original context signal is repeated and evolves over successive items in the same way as at input. For each signal, item nodes receive activation based on their initial pairing with context in the original sequence, and the winning item is selected and activates consistent output phonemes. Noise is added to this final selection process to induce errors. Where serial order errors do occur – that is, incorrect item nodes are selected – they tend to migrate to target-adjacent positions as a consequence of the high degree of overlap in the context nodes active in successive context states.

In addition to generating the classic experimental phenomena associated with the phonological loop such as the phonological similarity, word length, and articulatory suppression effects, this model simulates many of the features of serial order behavior that the phonological loop model on which it was based could not address. Consider first the serial position function. Primacy effects arise largely from the greater number of rehearsals received by early list items, and recall of both initial and final items is enhanced by the reduced degree of order uncertainty at these terminal list positions. A preponderance of order errors is also readily generated because context signals, like item representations, degrade with time. Thus on some occasions, the retrieved item representation will have been associated with an adjacent context signal, yielding recall of a list item at an incorrect output position. When items do migrate in simulations of the model, they show the bell-shaped migration function in which the distances traveled in the sequence are usually small rather than large, which has also been established in the behavioral data.

#### *2.04.2.1.3 The phonological loop and language*

Although the cognitive processes underpinning the phonological loop are well understood, one puzzle for many years was exactly why this system exists. It may have turned out to be useful for remembering telephone numbers, but why do we have the system in the first place? A number of possibilities were considered. One plausible hypothesis was that the phonological loop acts as a buffer for planned speech.

The presence of a phonological output buffer that stores the retrieved phonological specifications of intended lexical items and enables the smooth and rapid production of speech has long been recognized as a logical necessity by speech production theorists (e.g., Bock, 1982; Romani, 1992). There is, however, little evidence that the phonological store fulfills this function (see Gathercole and Baddeley, 1993 for review). It has consistently been found that adult neuropsychological patients with very severe deficits of verbal short-term memory leading to memory spans of only one or two items can nonetheless produce spontaneous speech normally: utterance length rates of hesitations and self-corrections are comparable to those of control adults (Shallice and Butterworth, 1977).

A second hypothesis was that the phonological loop provides an input buffer to incoming language that is consulted in the course of normal comprehension processes (Clark and Clark, 1977). Once again, findings from adult short-term memory patients provided the opportunity to test this hypothesis. The prediction was clear: if short-term memory plays a significant role in comprehension, the very low memory span of short-term memory patients should lead to substantial impairments in processing the meaning of language. Findings from many research groups and many different patients provided little support for this prediction. Despite severe deficits in phonological loop functioning, short-term memory patients typically had few difficulties in processing sentences for meaning, except under conditions in which lengthy, unusual, and ambiguous syntactic structures were used, or the sentences were essentially memory lists (see Vallar and Shallice, 1990; Caplan and Waters, 1990; Gathercole and Baddeley, 1993; for reviews). It therefore appears that although under most circumstances the language processor operates online without recourse to stored representations in the phonological loop, these representations may be consulted in an off-line mode to enable backtracking and possible re-analysis of spoken language under some conditions (McCarthy and Warrington, 1987).

There is, however, one area of language functioning in which the phonological loop appears to play a central role, and that is in learning the sound structure of new words. Evidence from many sources converges on this view. Studies of typically developing children have consistently found close and selective associations between measures of verbal short-term memory and knowledge of both native and foreign language vocabulary (e.g., Gathercole and Baddeley, 1989; Service, 1992; Cheung, 1996; Masoura and Gathercole, 1999). The accuracy of nonword repetition – in which a child hears a spoken nonword such as woogalamic and attempts to repeat it immediately – is particularly highly correlated with vocabulary knowledge, although so too are more conventional measures of verbal short-term memory such as digit span (Gathercole et al., 1994b). A similar link is found between verbal memory skills and the rate of learning nonwords in paired-associate learning paradigms, in which participants learn to associate unfamiliar phonological forms with either novel objects (Gathercole and Baddeley, 1990a, used toy monsters with names such as Pimas), unrelated words (such as fairy-kipser), or semantic attributes (e.g., bleximus is a noisy, dancing fish). Both of the latter examples are from a study reported by Gathercole et al. (1997), in which the phonological memory skills of the participating 5-year-old children were in contrast found to be independent of the ability to learn word–word pairs.

Further evidence that the phonological loop is involved in the long-term learning of phonological structures in particular has been provided by the study of individuals with developmental or acquired deficits in language learning. Specific language impairment (SLI) is a condition in which children fail to develop language at a normal rate despite normal intellectual function. Word learning represents a particular problem for affected children. It has consistently been found that children with SLI have substantial impairments of nonword repetition and of other measures of verbal short-term memory (e.g., Gathercole and Baddeley, 1990b; Bishop et al., 1996; Archibald and Gathercole, 2006). A corresponding neuropsychological patient, PV, had a severe deficit of the phonological loop, and was found to be completely unable to learn word–nonword pairings such as rose–svieti, but performed within the typical range on a word–word learning task (Baddeley et al., 1988). Experimental studies of paired-associate learning with normal adult participants have shown that word–nonword learning is disrupted by variables known to interfere with phonological loop functioning, such as phonological similarity and articulatory suppression (Papagno et al., 1991; Papagno and Vallar, 1992). In contrast, learning of word–word pairs is not influenced by these variables.

On this basis, it has been proposed that the primary function of the phonological loop is to support learning of the sound structures of new words in the course of vocabulary acquisition (Baddeley et al., 1998b). It is suggested that initial encounters with the phonological forms of novel words are represented in the phonological short-term store, and that these representations form the basis for the gradual process of abstracting a stable specification of the sound structure across repeated presentations (Brown and Hulme, 1996). Conditions that compromise the quality of the temporary phonological representation in the phonological loop will reduce the efficiency of the process of abstraction and result in slow rates of learning. In a recent review of this theory and associated evidence, Gathercole (2006) has suggested use of the phonological loop to learn new words is a primitive learning mechanism that dominates at the early stages of learning a language and remains available as a strategy throughout life. However, once a substantial lexicon is established in a language, word learners increasing rely on lexically mediated learning of new words, thereby building on the phonological structures that they have already acquired.

#### *2.04.2.1.4 Summary*

The phonological loop model advanced by Baddeley (1986), consisting of a short-term store and a subvocal rehearsal process, is the most influential current account of verbal short-term memory. Convergent evidence for the model is provided from a range of research traditions including experimental cognitive psychology, developmental psychology, neuropsychology, and neuroimaging. A similar diverse range of findings indicate that the phonological loop plays a key role in vocabulary acquisition (Baddeley et al., 1998; Gathercole, 2006).

The successful implementation of the model in the form of a connectionist network by Burgess and Hitch (1992) is an important development that has stimulated competing computational models of serial recall with distinct architectures. The network model has also been further developed to simulate learning of novel sequences by the phonological loop (Burgess and Hitch, 1999). The availability of detailed models of short-term memory and the reciprocal stimulation of empirical findings and computational simulations is a sign of advanced theoretical development that is in large part due to the guiding influence of the phonological loop concept on this field over many years.

### 2.04.2.2 The Visuospatial Sketchpad

#### *2.04.2.2.1 Theory and empirical phenomena*

The second slave system of the working memory model is the visuospatial sketchpad, specialized in the storage and manipulation of information that can be represented in terms of either visual or spatial characteristics. Short-term memory for visuospatial material is associated with increased activity in the right hemisphere regions of the inferior prefrontal cortex, anterior occipital cortex, and posterior parietal cortex, and acquired damage to these regions of the brain leads to selective deficits in remembering these domains of material (see Gathercole, 1999, for review).

Several tasks have been designed to tap the visuospatial sketchpad. These include recognizing the pattern of filled squares in a two-dimensional grid (Phillips and Christie, 1977; Wilson et al., 1987), remembering the order in which a set of blocks are tapped (often known as the Corsi blocks task), using a grid to generate a mental image corresponding to a set of spatial instructions (Brooks, 1967), and recalling the path drawn through a maze (Pickering et al., 2001).

Like its sister slave system the phonological loop, the sketchpad has now been fractionated into two distinct but interrelated components: A visual store or cache that preserves the visual features of perceived or internally generated objects and a spatial or sequential component that may serve a recycling function analogous to subvocal rehearsal (Logie, 1995). The strongest evidence for the separation of the sketchpad into these two components is provided by studies of neuropsychological patients with acquired brain lesions resulting in selective impairments of visual storage but preserved spatial short-term memory (Hanley et al., 1991) and converse deficits in spatial but not visual short-term memory (Della Sala et al., 1999; Della Sala and Logie, 2003).

Dual task studies have played an important role in illuminating the functional organization of the visuospatial sketchpad. One popular method for tapping the capacity for the generation and temporary storage of spatial material is the Brooks (1967) task, in which the participant is presented with a $4 \times 4$ empty grid in which one particular cell was designated as the starting square. The experimenter then gives a series of verbal instructions which participants are encouraged to remember by mentally filling in the grid, as shown in **Figure 4**. Following the

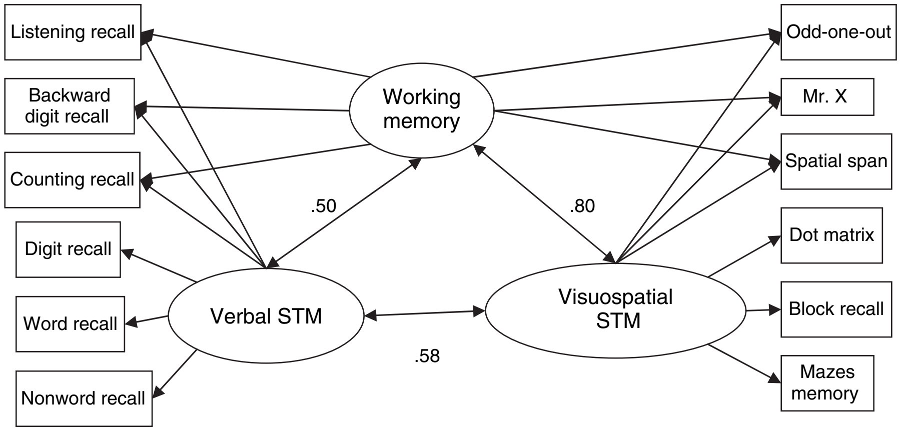


**Figure 4** Measurement model of working memory, based on data from children aged 4–11 years. STM, short-term memory. From Alloway TP, Gathercole SE, and Pickering SJ (2006) Verbal and visuo-spatial short-term and working memory in children: Are they separable? *Child Dev.* 77: 1698–1716; used with permission from Blackwell Publishing.

instructions, participants recall the sequence by filling in the grid with the numbers. This condition facilitates the use of spatial imagery and hence the visuospatial sketchpad. In a control condition which does not encourage the use of such spatial imagery, the spatial terms up, down, left, right were replaced by the nonspatial adjectives good, bad, slow, and fast to yield nonsensical sentences. Presumably, recall in this condition was supported by the phonological loop rather than the sketchpad.

Evidence that participants use mental imagery to mediate performance in the spatial but not the nonsense condition is provided by the superior levels of recall accuracy in the former condition (Brooks, 1967). In a systematic study of the effects of concurrent activities on memory performance in the two cases, Baddeley and Lieberman (1980) reported further evidence that distinct components of working memory are employed in the two conditions. Performing a concurrent task – tracking an overhead swinging pendulum – disrupted recall in the spatial but not the nonsense condition. Thus, spatial recall appears to be selectively impaired by the encoding of unrelated spatial content, consistent with the employment of a spatial code to mediate recall performance.

Subsequent investigations indicate that eye movements may play a key role in the maintenance of spatial images in the sketchpad. Postle et al. (2006) reported a series of experiments showing that voluntary eye movements impair memory for spatial locations but not for nonspatial features of visual objects, providing further support for a distinction between visual and spatial components of the sketchpad. Other studies have shown that the engagement of other movement systems such as hands (finger tapping), legs (foot tapping), and arms exerts similar disruptive influences on memory for spatial sequences such as Corsi block recall (e.g., Smyth and Scholey, 1988). It therefore appears that the maintenance of spatial representations in the sketchpad is supported by a central motor plan that is not specific to any particular effector system, by which is recruited the planning and execution of movements in the full range of motor systems.

There is some evidence that the visual storage component of the spatial sketchpad is selectively disrupted by the concurrent perception of irrelevant visual features. In a series of studies reported by Quinn and McDonnell (1996), memory for detailed visual characteristics was selectively impaired by visual noise that corresponded to a randomly flickering display of pixels similar to an untuned television screen that participants were required to view but asked to disregard. This finding is important, as it is directly analogous to the irrelevant speech effect in verbal serial recall (Colle and Welsh, 1976), which has been interpreted as reflecting obligatory access to the short-term store component of the phonological loop for auditory speech material.

One interpretational problem raised by many studies of visuospatial short-term memory is the extent to which these and other similar tasks reflect a genuinely distinct component of working memory, or alternatively draw on the more general resources of the central executive. The central executive, which is described in more detail in the following section, is a limited-capacity domain-general system capable of supporting a wide range of cognitive activities. Several different lines of evidence indicate that the central executive plays a major role in many visuospatial short-term memory tasks. Performance on visual storage tasks has been found to be strongly disrupted by concurrent activities that lack an overt visuospatial component but which are known to tax the central executive, such as mental arithmetic (Phillips and Christie, 1977; Wilson et al., 1987). Also, studies of individual differences have consistently shown that measures of visuospatial short-term memory are much more closely associated with performance on central executive tasks than are phonological loop measures, in both typically developing children (Gathercole et al., 2004a, 2006a; Alloway et al., 2006) and in a clinical study of adults with bipolar mood disorder (Thompson et al., 2006).

#### *2.04.2.2.2 Summary*

Although current understanding of the detailed cognitive processes involved in visuospatial short-term memory is less well advanced than that of the phonological loop, two basic facts have now been established. First, the sketchpad functions independently of the phonological loop – it is associated with activity in the right rather than the left hemisphere of the brain and is selectively disrupted by concurrent activities that do not influence the phonological loop. Second, the processes involved in manipulating and storing visual features and spatial patterns appear to be distinct from one another, again showing neuropsychological and experimental dissociations. It is rather less clear to what extent the visuospatial sketchpad represents a distinct component of working memory that is dissociable from the central executive.

### 2.04.2.3 The Central Executive

At the heart of the working memory model is the central executive, responsible for the control of the working memory system and its integration with other parts of the cognitive system. The central executive is limited in capacity, and is closely linked with the control of attention and also with the regulation of the flow of information within working memory, and the retrieval of material from more permanent long-term memory systems into working memory. Neuroimaging studies indicate that the frontal lobes of both hemispheres of the brain, and particularly of the prefrontal cortex, are activated by activities known to tax the central executive (See Collette and Van der Linden, 2002; Owen et al., 2005, for reviews).

#### *2.04.2.3.1 The supervisory attentional system*

In 1986, Baddeley suggested that central executive may correspond in part at least to the model of the supervisory attentional system (SAS) advanced by Shallice (1982) to explore the control of attention in action. The SAS has two principal components. The contention scheduling system consists of a set of schemas, which are organized structures of behavioral routines that can be activated by either internally or externally generated cues. When a schema reaches a particular level of activation, it is triggered and the appropriate action or set of actions is initiated. Thus, we have schemas that govern all our skilled behaviors: walking and talking, breathing and jumping, opening doors and using a telephone. Schemas can be hierarchically organized. Skilled car drivers, for example, will have a driving schema that is composed of linked subschemas such as steering and braking schemas. Many of our actions are governed by the automatic activation of these schemas in response to environmental cues. So, once we are behind the wheel of a moving car, the sight of a red brake light in the car in front will probably be sufficient to trigger the automatic activation of the braking subschema. Activation levels of all incompatible schemas (such as the accelerating schema, in this case) are inhibited when a schema is triggered.

The second component, the SAS, controls behavior via a very different process. The SAS can directly activate or inhibit schemas, thereby overriding their routine triggering by the contention scheduling system. The intervention of the SAS corresponds to volitional control and prevents us from being endless slaves to environmental cues – it allows us to choose to change the course of our actions at will. However, because the SAS is a limited capacity system, there are finite limits on the amount of attentional control we can apply to our actions.

Baddeley's (1986) suggestion was that the central executive corresponds to the limited-capacity SAS. He also proposed that two types of behavioral disturbance associated with damage to the frontal lobes arise from malfunctioning of the central executive, and coined the term dysexecutive syndrome to describe this disorder. These neuropsychological patients are typically characterized by one of two possible types of behavior. Perseveration is a form of behavioral rigidity in which the individual continually repeats the same action or response. An example would be greeting a newcomer by saying "Hello" and then continuing to make the same response many times to the same individual, increasingly inappropriately. Distractibility consists of unfocused behavior in which the individual fails to engage in meaningful responses but may, for example, continuously walk around a room manipulating objects. Baddeley suggested that such individuals have an impairment in central executive resources that reduces their capacity for volitional control of behavior via the SAS, which is instead dominated by the contention scheduling system. Perseveration results when a schema becomes highly activated and cannot be effectively inhibited by the SAS to allow the triggering of other appropriate behaviors, and distractibility results from the background triggering of behavior by environmental cues with no overriding focus by the SAS.

This conceptualization of the central executive has proved useful in guiding the development of laboratory tasks that engage the central executive. One such task is random generation (Baddeley, 1986). In a typical task, the participant is required to generate in a random manner exemplars from a familiar category, such as digits or letters, paced by a metronome. The importance of generating random sequences rather than stereotyped ones such as 1, 2, 3 or a, b, c is emphasized. In 1998, Baddeley et al. (1998a) conducted a series of experiments to investigate the hypothesis that the central executive is needed to intervene to override the activation of stereotyped response sequences in this task. There were several key findings consistent with this view. First, the degree of randomness of the sequences generated by the participants diminished (i.e., the responses became more stereotyped) when the generation rate was increased. This result indicates that the randomness of the responses was constrained by a limited capacity process. Second, the degree of randomness of the generated sequences was not impaired when the task was combined with other activities requiring stereotyped responses such as counting, but was substantially disrupted by nonstereotyped concurrent activities such as maintaining a digit load or generating exemplars of semantic categories. Applying the logic of dual-task methodology, it appears that both tasks tap a common limited-capacity mechanism, the central executive.

#### *2.04.2.3.2 Complex memory span*

The central executive also plays a key role in complex memory span tasks, which require both processing and storage. The first reported complex span task, reading span, was developed by Daneman and Carpenter in 1980. In this task, participants must read aloud each of a sequence of printed sentences, and at the end of the sequence they must recall the final word of each sentence in the same order as the sentences were presented. The number of sentences read on each trial is then increased until the point at which the participant can no longer reliably recall the sequence of final words. Findings from this task were impressive – complex memory span scores were highly correlated with the performance of the participating college students on their scholastic aptitude tests completed on entry to college. Importantly, the correlations with scholastic aptitude were considerably higher than those found with storage-only measures of verbal short-term memory.

A range of other complex span paradigms have been subsequently developed, all sharing the common feature of requiring both memory storage while participants are engaged in significant concurrent processing activity. A listening span version of the reading span test in which the sentences were heard rather than read by participants was employed by Daneman and Carpenter (1983), and was found to be correspondingly associated with academic abilities. Complex span tasks suitable for use by young children have also been developed. One popular task is counting span, in which the child has to count the number of elements in a series of visual displays, and at the end of the sequence to recall the totals of each array, in the order of presentation (Case et al., 1982). The odd-one-out task (Russell et al., 1996; Alloway et al., 2006) is a complex memory span task that requires visuospatial rather than verbal storage and processing (see also, Shah and Miyake, 1996). Participants view a series of displays each containing three unfamiliar objects, two identical and one different. The task is to point to the location of the odd one out, and then at the end of the sequence to recall the sequence of spatial locations of the different items. In other complex span tasks, the material to be stored is distinct from the contents of the processing activity. An example of one such task is operation span (Turner and Engle, 1989), in which participants attempt to recall digits whose presentation is interpolated with a sequence of simple additions that must be completed.

Despite the large degree of variation in both the processing and storage demands of the different complex memory span tasks, a highly consistent pattern of findings has emerged. Performance on such tasks is strongly related to higher-level cognitive activities such as reasoning and reading comprehension (e.g., Kyllonen and Christal, 1990; Engle et al., 1992), and also to key areas of academic achievement during childhood such as reading and mathematics (e.g., Swanson et al., 1996; Hitch et al., 2001; Jarvis and Gathercole, 2003; Gathercole et al., 2004b, 2006a; Geary et al., 2004; Swanson and Beebe-Frankenberger, 2004). In the majority of these studies, associations with learning were much higher for complex memory span measures than measures such as digit span of verbal short-term memory. Corresponding closer links with measures of intellectual functioning in adulthood such as reading comprehension, scholastic aptitude, and fluid intelligence have also been consistently found in adult populations (for reviews, see Daneman and Merikle, 1996; Engle et al., 1999b).

In order to understand why complex span measures of working memory performance are so strongly associated with learning abilities and other measures of high-level cognition, it is necessary first to consider what cognitive processes these measures tap. It has been suggested that the processing portions of these tasks are supported by the domain-general resources of the central executive, whereas the storage requirements are met by the respective domain-specific slave system (Baddeley and Logie, 1999). By this view, both the central executive and the phonological loop contribute to performance on verbal complex span tasks such as reading span, listening span, and counting span, whereas performance on visuospatial complex span tasks is mediated by the central executive and the visuospatial sketchpad.

There is now substantial evidence to support this proposal. A common processing efficiency factor has been found to underlie both verbal and visuospatial complex memory tasks (Bayliss et al., 2003). Two recent studies have investigated the latent factor structure underlying individuals' performance on both simple (storage-only) and complex span measures in both the verbal and visuospatial domains, in children (Alloway et al., 2006) and in adults (Kane et al., 2004). In both cases, the best-fitting model is a structure consisting of distinct verbal and visuospatial short-term storage components (corresponding to the phonological loop and visuospatial sketchpad, respectively), plus a domain-general factor corresponding to the central executive. A summary of the factor structure of the model from Alloway et al. (2006) is shown in **Figure 4**. It can be seen that the complex span tasks load both on the domain-general factor and the respective domain-specific storage system. These data provide an impressive degree of support for the basic structure of the working memory model.

So why is it the case that slow rates of academic learning therefore characterize children who perform poorly on complex memory measures of working memory (e.g., Pickering and Gathercole, 2004; Gathercole et al., 2006a)? We have suggested that the reason is that working memory acts as a bottleneck for learning (Gathercole, 2004; Gathercole et al., 2006b). The acquisition of knowledge and skill in complex domains such as reading and mathematics requires the gradual accumulation of knowledge over multiple learning episodes, many of which will take place in the structured learning environment of the classroom. Learning is thus an incremental process that builds upon the knowledge structures and understanding that have already been acquired: any factor that disturbs this acquisition process will have deleterious consequences for the rate of learning, as the necessary foundations for progress will not be in place. It is proposed that working memory capacity is one of the factors that constrains learning success in potential learning episodes. Many classroom activities require the child to keep information in mind while engaging in another cognitive activity that might be very demanding for that individual. Mental arithmetic is an example of such a demanding working memory activity for adults. In children, whose working memory capacity is considerably smaller and who do not have the same bedrock of stored knowledge and expertise to support cognitive processing, working memory challenges of a comparable magnitude are present in much simpler activities, such as writing sentences, adding up totals of objects displayed on cards, or detecting rhyming words in a poem read by the teacher. Children with poor working memory capacities will face severe difficulties in meeting the demands of these situations and, as a result of their working memory overload, will fail in part or all of the learning activity. Such situations represent missed learning opportunities and if they occur frequently, will result in a slow rate of learning.

### 2.04.2.4 The Episodic Buffer

The episodic buffer is the most recent addition to the working memory model, and was first outlined in a seminal paper by Baddeley in 2000 (Baddeley, 2000).

In this article, Baddeley argued the need for a separate buffer capable of representing and integrating inputs from all subcomponents of working memory and from long-term memory systems in a multidimensional code.

One justification for the episodic buffer is that it solves the binding problem, which refers to the fact that although the separate elements of multimodal experiences such as seeing an object moving and hearing a sound are experienced via separate channels leading to representations in modality-specific codes, our perception is of the event as a coherent unitary whole. At some point, the representations must therefore converge and be chunked together and experienced consciously as a single object or event; Baddeley's suggestion was that the episodic buffer may fulfill this function.

Other evidence also points to a close interface between the subcomponents of working memory and other parts of the cognitive system. It has long been known that meaningful sentences are much better remembered than jumbled sequences of words, with memory spans as high as 16 words compared with the six or seven limit for unrelated words (Baddeley et al., 1987). This indicates that representations in the phonological loop are integrated at some point with conceptual representations arising from the language processing system. Importantly, patients with acquired impairments of verbal short-term memory show reduced memory span for sentences as well as for word lists, but still show the relative advantage of meaningful over the meaningless material. Patient PV, for example, had a sentence span of five and a word span of one (Vallar and Baddeley, 1984). As PV's long-term memory was entirely normal, the reduction in her sentence span must arise from the point of interaction between verbal short-term memory (or the phonological loop). Baddeley (2000) proposed that the episodic buffer may provide the appropriate medium for linking the phonological loop representations with those from long-term memory, and that the central executive may control the allocation of information from different sources into the buffer.

The characteristics of the episodic buffer have been explored in a subsequent experimental programme by Baddeley and collaborators. One line of investigation has looked into whether the episodic buffer plays a role in the binding of different visual features of objects into chunks by comparing memory for arrays of colors or shapes with memory for bound combinations of these features (Allen et al., 2006). In a series of experiments, recognition memory for visually presented objects was tested by presenting an array of objects followed by a probe; the participants' task was to judge whether the probe was present in the original display or not. Across conditions, recognition memory was tested either for shape by presenting a display of different unfilled shapes, for color with a display of squares of different colors, or for both color and shape by presenting objects composed of unique shape/color combinations. In line with previous findings from this paradigm (Wheeler and Treisman, 2002), recognition performance was found to be as accurate in the feature combination as the single feature conditions. Thus, feature binding appears to be a relatively efficient process.

Allen et al. (2006) investigated whether this binding process depends on central executive resources, as might be predicted from the working memory model shown in **Figure 1**, in which information is fed into the episodic buffer from the central executive. To test this possibility, participants also performed demanding concurrent tasks that would be expected to require executive resources – counting backwards and retaining a near-span digit load – while viewing the object arrays. The results were clear: although recognition memory was generally less accurate under dual task conditions, memory for bound features was not selectively disrupted. The only condition that did lead to a greater impairment of recognition for feature combinations than single features was one that involved sequential rather than simultaneous presentation of objects.

On the basis of these findings, Allen et al. concluded that binding the features of simple visual features takes place in the visuospatial sketchpad and does not require executive support. However, it was suggested that storage of such automatically bound information is fragile and may fall apart when further feature combinations need to be encoded and stored in visuospatial memory.

The possible role of the attentional resources of the central executive in integrating linguistic information with representations in the phonological loop in the episodic buffer was investigated by Jefferies et al. (2004). The main focus of this study was the substantial advantage found in the immediate recall of prose compared with unrelated words, which Baddeley (2000) had suggested may be mediated by the integration of linguistic and phonological information in the episodic buffer. Jefferies et al.

conducted a series of experiments in which the relative difficulty of different kinds of lists was equated for individual participants. Thus, an example of an unrelated word list that corresponds to 50% above span for an average participant with a word span of six was the nine items essay, marmalade, is, lots, clowns, wine, spaces, often, a. In the sentence condition of a corresponding level of difficulty, an average participant with a sentence span of 13 would receive the following sequence of unrelated sentences for immediate recall: Railway stations are noisy places. Guns can cause serious injuries. Water is boiled in kettles. Pink roses are pretty flowers. In a further story condition, the sentences were thematically related, as in the following example: A teenage girl loved buying clothes. She went shopping with her mom. They traveled into town by bus.

The possible engagement of attentional processes associated with the central executive was investigated by comparing the impact of a continuous reaction time (CRT) task completed during the presentation of the memory sequence on performance in the different conditions. Following Craik et al. (1996), the CRT task involved pressing one of four keys corresponding to the spatial location of a visual target that appeared on a computer screen; as soon as the key was pressed, the next stimulus was presented. This task is known to place significant demands on controlled attentional processing. If the central executive does play a crucial role in loading phonological and linguistic information into the episodic buffer where it can be integrated into a multidimensional code underpinning sentence span, a selective decrement in the recall of sentences relative to unrelated words would be expected in the concurrent CRT conditions.

Jefferies et al. (2004) found that recall of unrelated words was more or less unaffected by the concurrent task, as was the recall of thematically organized material in the story condition. These findings indicate that the use of the phonological loop places few demands on attentional resources, and also that the activation of preexisting representations relating to the semantic and syntactic content of the stories occurs relatively automatically. In contrast, CRT did markedly impair performance in the condition involving the recall of unrelated sentences. It therefore appears that substantial attentional support from the central executive is required for the retention of unrelated chunks of linguistic information, possibly within the episodic buffer.

Although the study of the episodic buffer is still in its infancy, the concept is being refined in light of new evidence and is proving useful in guiding research on memory for relatively complex forms of material. The simple idea that the central executive is required to feed information through to the episodic buffer for the purposes of feature binding has not received strong support from the research completed so far: there is little evidence for central executive involvement in either the binding of simple visual features (Allen et al., 2006) or in the recall of coherent prose, although attentional support does appear to be crucial for the temporary retention of chunks of unrelated linguistic information (Jefferies et al., 2004). Ongoing and future research designed to delineate the precise conditions under which the central executive and episodic buffer interact seems certain to provide further fruitful insights into the role played by working memory in the storage and manipulation of complex and structured information.

### 2.04.2.5 Other Models of Working Memory

The multicomponent model of working memory initially advanced by Baddeley and Hitch (1974) is the most enduring and influential theoretical framework in the field. Its success rests with the breadth of scope of the model – incorporating verbal and visuospatial short-term memory, as well as attentional processes – and also with the capacity of the model to evolve in light of incoming evidence. Although the original tripartite structure of the 1974 model has been largely preserved, each component has been elaborated and differentiated over the intervening years, largely but not exclusively by using the dual task methodology to identify distinct subcomponents of the system. The model has also proved successful in accommodating evidence from a wide range of empirical traditions including cognitive development, neuropsychology, and neuroscience in addition to experimental psychology. It is, however, by no means the only model of working memory, and there are currently several other conceptualizations that are proving to be highly effective in guiding research and thinking in the area. Some of the significant alternative theoretical accounts of working are outlined in the following.

#### *2.04.2.5.1 Attentional based models*

One influential theoretical account of working memory of this type is Cowan's (1995, 2001) embedded process model, summarized in **Figure 5**. According to this model, long-term memory can be partitioned

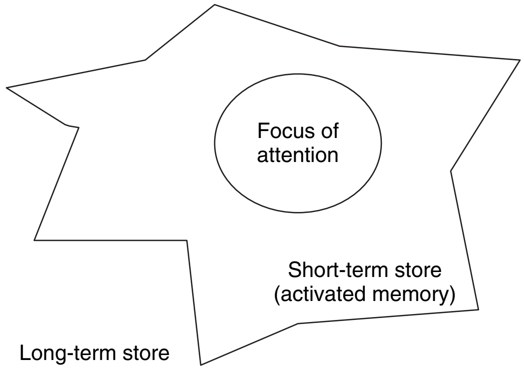


**Figure 5** Cowan's (1995) embedded process model of working memory.

in three ways: the larger portion that has relatively low activation at any particular point in time, a subset that is currently activated as a consequence of ongoing cognitive activities and perceptual experience, and a smaller subset of the activated portion that is the focus of attention and conscious awareness. The focus of attention is controlled primarily by the voluntary processes of the executive system that are limited in capacity in chunks. Recent work indicates that typically between three and five chunks of information can be maintained in the focus of attention (Cowan, 2001; see also Chen and Cowan, 2005; Cowan et al., 2005). In contrast, long-term memory activation is time-limited and decays rapidly without further stimulation.

Cowan et al. (2005) have put forward an interpretation of complex memory span performance and its links with scholastic aptitude measures that is markedly divergent from the explanation based on the working memory model considered in the section titled 'The central executive.' By this account, the crucial feature of complex span tasks is that the processing activity prevents the usual deployment of control strategies such as rehearsal and grouping, and thus exposes more directly the scope of the focus of attention, as indexed by the number of chunks that can be maintained simultaneously. Learning ability will be constrained by having a relatively poor scope of attention, laid bare by complex memory span tasks.

An attentional-based account of working memory function has been also advanced by Engle and associates (e.g., Engle et al., 1999b). In some respects, Engle's model shares a similar architecture with the Baddeley and Hitch (1974) framework, combining domain-specific storage of verbal and visuospatial material with controlled attention. The detailed functioning of the components is, however, quite different. Short-term memory consists of traces that have exceeded an activation threshold and represent pointers to specific regions of long-term memory. They therefore do not represent temporary representations in a specialized temporary store, as in the phonological loop. Controlled attention is a domain-general resource that can achieve activation through controlled retrieval, maintain activation, and block interference through the inhibition of distractors.

Unsworth and Engle (2006) have recently put forward a new explanation of why complex memory span tasks correlate more highly with measures of higher-order cognitive function than simple memory span, based upon the distinction between primary and secondary memory. According to this account, memory items that have been recently encountered are held in primary memory, and may also be transferred into the more durable secondary memory system (Waugh and Norman, 1965). The processing activity in complex span tasks displaces items from primary memory, so that recall performance is supported principally by residual activation in secondary memory. Unsworth and Engle suggest that it is the ability to retrieve items from secondary memory that is crucial to more cognitive activities such as reasoning. Note that this interpretation is somewhat similar to that advanced by Cowan et al. (2005); in both cases, the claim is that learning is served most directly by the quality of activation of long-term memory, and not by the capacity of the controlled attention process that generates conscious experience.

#### *2.04.2.5.2 The resource-sharing model*

A contrasting theoretical perspective on working memory was provided by Daneman and Carpenter (1980, 1983; Just and Carpenter, 1992). These researchers conceived working memory as an undifferentiated resource that could be flexibly deployed either to support temporary storage or processing activity. By this account, individuals with relatively low span scores on complex memory span tasks were relatively unskilled at the processing element of the activity (reading, in the case of reading span), thereby reducing the amount of resource available for storage of the memory items. This idea that working memory is a single flexible system fueled by a limited capacity resource that can be flexibly allocated to support processing and storage was applied by Case et al. (1982) to explain developmental increases in working memory performance across the childhood years.

They proposed that the total working memory resource remains constant as the child matures, but that the efficiency of processing increases, releasing additional resource to support temporary storage. Consistent with this view, Case et al. found in a study of 6- to 12-year-old children that counting spans were highly predictable from individual counting speeds. Furthermore, counting spans were reduced to the level typical of 6-year-old children when adults' counting efficiency was reduced by requiring the use of nonsense words rather than digits to count sequences. It was concluded that the decreased memory spans resulted from the greater processing demands imposed by the unfamiliar counting task, leading to a processing/storage trade-off that diminished storage capacity.

#### 2.04.2.5.3 Time-based theories

The resource-sharing model of working memory has been challenged substantially in recent years. Towse and Hitch (1995) proposed that participants do not process and store material at the same time in complex span tasks as assumed by the resource-sharing approach, but instead strategically switch between the processing and storage elements of the task. Evidence consistent with this task-switching model has been provided in a series of studies that have either varied counting complexity while holding retention interval constant (Towse and Hitch, 1995) or manipulated retention requirements in counting, operation, and reading span tasks, while holding constant the overall processing difficulty (Towse et al., 1998). In each case, the period over which information was stored was a better predictor of complex memory span than the difficulty of the processing activity. This has led to the claim that complex memory span is constrained by a time-based loss of activation of memory items (Hitch et al., 2001).

The consensus view at present is that no single factor constrains complex memory span (Miyake and Shah, 1999; Bayliss et al., 2003; Ransdell and Hecht, 2003). A more complex model recently advanced by Barrouillet and colleagues (Barrouillet and Camos, 2001; Barrouillet et al., 2004) combines concepts of both temporal decay and processing demands in a single metric of cognitive cost that is strongly related to performance on complex span tasks. In this model, the cognitive cost of a processing task is measured as the proportion of time that it requires limited-capacity attentional resources, for example, to support memory retrievals. When attention is diverted from item storage to processing in this way, memory representations cannot be refreshed and therefore decay with time. The heaviest cognitive costs and therefore the lowest levels of complex span performance are therefore expected under conditions in which there is the greatest ratio of number of retrievals to time. Experimental findings reported by Barrouillet et al. (2004) are entirely consistent with this prediction. Using a complex memory span paradigm in which they separately manipulated the rate of presentation of the memory items and the number of intervening items to be processed, complex memory span was found to be a direct linear function of the cognitive cost of the processing activity, computed as a ratio of the number of processing items divided the period over which they were presented. Thus, processing intervals that had relatively high loads (in other words, a relatively large number of items per unit time) were associated with lower span scores than processing intervals with low cognitive loads (low numbers of items per unit time).

#### 2.04.2.5.4 Summary

In this section, a number of alternative theoretical accounts of working memory have been considered. It can be argued that some of these conceptualizations provide valuable specifications of the nature of central executive processes and are not necessarily incompatible with the Baddeley and Hitch (1974; Baddeley, 2000) model. Certainly, the emphasis on time-based loss of information by Towse and Hitch and the ideas of Barrouillet and colleagues concerning cognitive load could readily be accommodated in an elaborated model of the central executive and its interface with the phonological loop. The majority of these alternative approaches also emphasize the role of attention in working memory, a concept given prominence also by Baddeley (1986). However, other claims that working memory is an activated subset of long-term memory and does not exist as a temporary storage medium distinct from preexisting knowledge are less easy to reconcile.

## 2.04.3 Overview

The ability to hold information in mind for brief periods of time, termed working memory by cognitive psychologists, is an essential feature of our everyday mental life. The purpose of this chapter is to provide a contemporary overview of current theoretical understanding of the cognitive processes of working memory. According to the influential model advanced originally by Baddeley and Hitch (1974) and revised and elaborated over the subsequent years (Baddeley, 1986, 2000; Burgess and Hitch, 1992, 1999), working memory consists of an attentional controller, the central executive, supplemented by slave systems specialized in the storage of verbal and nonverbal information (the phonological loop and visuospatial sketchpad, respectively). An additional component is the episodic buffer, capable of integrating information from different parts of working memory and other parts of the cognitive system. Each component of the model is limited in capacity.

This relatively simple model of working memory has proved capable of accommodating a wide range of empirical findings. Its fractionated structure has been informed by findings from experimental studies using dual task methods, by developmental dissociations in studies of children, and by evidence of distinct underlying brain from the fields of neuropsychology and neuroimaging. In the area of the phonological loop in particular, understanding of the underlying cognitive processes is sufficiently well advanced to allow the development of a computational model capable of simulating many detailed aspects of verbal short-term memory behavior.

Two components of the working memory model – the central executive and phonological loop – appear to play key roles not only in the temporary retention of information, but also in supporting longer-term learning, particularly during the childhood years. The phonological loop is important for learning the sound patterns of new words in the course of acquisition of vocabulary in native and foreign languages, whereas the central executive mediates academic learning in areas including reading and mathematics. Detailed theoretical accounts of the possible causal roles of working memory in these elements of learning are considered.

There are also several alternative theoretical accounts of working memory that are currently proving useful in guiding further research and understanding in this field. Some of these theories conceive of working memory as the subset of representations in long-term memory that have been activated either automatically via our interactions with the environment or effortfully, by being the focus of a consciously controlled attentional resource. Whereas the role played by attention is acknowledged in almost all current models of working memory, the distinction between models that assume specialized temporary storage mechanisms and those that see working memory as a property of preexisting knowledge representations is a fundamental one, yet to be resolved by empirical evidence. A further common feature of many theories is that time-based forgetting is a crucial feature of working memory.

Research in the field of working memory continues, stimulated by the availability of detailed theoretical accounts that guide empirical investigations of both typical and atypical working memory functioning. There is also increasing recognition that our current understanding of working memory can be put to more practical use, particularly in the fields of education and remediation (e.g., Gathercole and Alloway, in press). In this respect, working memory represents a strong example of how laboratory investigations of basic cognitive processes have the potential to enhance less esoteric elements of our everyday cognitive experience.

## References


Allen RJ, Baddeley AJ, and Hitch GJ (2006) Is the binding of visual features in working memory resource-demanding? *J. Exp. Psychol. Gen.* 135: 298–313.

Alloway TP, Gathercole SE, and Pickering SJ (2006) Verbal and visuo-spatial short-term and working memory in children: Are they separable? *Child Dev.* 77: 1698–1716.

Archibald LMD and Gathercole SE (2006) Short-term and working memory in specific language impairment. *Int. J. Comm. Disord.* 41: 675–693.

Baddeley AD (1996) Exploring the central executive. *Q. J. Exp. Psychol.* 49A: 5–28.

Baddeley AD (2000) The episodic buffer: A new component of working memory? *Trends Cogn. Sci.* 4: 417–422.

Baddeley AD (1986) *Working Memory*. Oxford: Oxford University Press.

Baddeley AD and Hitch G (1974) Working memory. In: Bower G (ed.) *The Psychology of Learning and Motivation*, pp. 47–90. New York: Academic Press.

Baddeley AD and Lieberman K (1980) Spatial working memory. In: Nickerson RS (ed.) *Attention and Performance,* VIII, pp. 521–539. Hillsdale, NJ: Lawrence Erlbaum Associates.

Baddeley AD and Logie RH (1999) The multiple-component model. In: Miyake A and Shah P (eds.) *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*, pp. 28–61. New York: Cambridge University Press.

Baddeley AD, Thomson N, and Buchanan M (1975) Word length and the structure of short-term memory. *J. Verb. Learn. Verb. Behav.* 14: 575–589.

Baddeley AD, Lewis VJ, and Vallar G (1984) Exploring the articulatory loop. *Q. J. Exp. Psychol.* 36: 233–252.

Baddeley AD, Papagno C, and Vallar G (1988) When long-term learning depends on short-term storage. *J. Mem. Lang.* 27: 5876–5896.

Baddeley AD, Emslie H, Kolodny J, and Duncan J (1998a) Random generation and the executive control of working memory. *Q. J. Exp. Psychol.* 51A: 819–852.

Baddeley AD, Gathercole SE, and Papagno C (1998b) The phonological loop as a language learning device. *Psychol. Rev.* 105: 158–173.

Barrouillet P and Camos V (2001) Developmental increase in working memory span: Resource sharing or temporal decay? *J. Mem. Lang.* 45: 1–20.
Barrouillet P, Bernadin S, and Camos V (2004) Time constraints and resource sharing in adults' working memory spans. *J. Exp. Psychol. Gen.* 133(1): 83–100.
Bayliss DM, Jarrold C, Gunn DM, and Baddeley AD (2003) The complexities of complex span: Explaining individual differences in working memory in children and adults. *J. Exp. Psychol. Gen.* 132: 71–92.
Bishop DVM and Robson J (1989) Unimpaired short-term memory and rhyme judgment in congenitally speechless individuals: Implications for the notion of articulatory coding. *Q. J. Exp. Psychol.* 41A: 123–140.
Bishop DVM, North T, and Donlan C (1996) Nonword repetition as a behavioural marker for inherited language impairment: Evidence from a twin study. *J. Child Psychol. Psychiatry* 37: 391–403.
Bjork EL and Healy AF (1974) Short-term order and item retention. *J. Verb. Learn. Verb. Behav.* 13: 80–97.
Bock JK (1982) Towards a cognitive psychology of syntax: Information processing contributions to sentence formulation. *Psychol. Rev.* 89: 1–49.
Brooks LR (1967) The suppression of visualisation by reading. *Q. J. Exp. Psychol.* 19: 289–299.
Brown GDA and Hulme C (1996) Modeling item length effects in memory span: No rehearsal needed? *J. Mem. Lang.* 34: 594–621.
Brown GDA, Preece T, and Hulme C (2000) Oscillator-based memory for serial order. *Psychol. Rev.* 107: 127–181.
Burgess N and Hitch GJ (1992) Toward a network model of the articulatory loop. *J. Mem. Lang.* 31: 429–460.
Burgess N and Hitch GJ (1999) Memory for serial order: A network model of the phonological loop and its timing. *Psychol. Rev.* 106: 551–581.
Caplan D, Rochon E, and Waters GS (1994) Articulatory length and phonological determinants of word-length effects in span tasks. *Q. J. Exp. Psychol. A* 45: 177–192.
Caplan D and Waters GS (1990) Short-term memory and language comprehension: A critical review of the psychological literature. In: Vallar G and Shallice T (eds.) *Neuropsychological Impairments of Short-Term Memory*, pp. 337–389. Cambridge: Cambridge University Press.
Case R, Kurland DM, and Goldberg J (1982) Working memory capacity as long-term activation: An individual differences approach. *J. Exp. Psychol. Learn. Mem. Cogn.* 19: 1101–1114.
Chen ZJ and Cowan N (2005) Chunk limits and length limits in immediate recall: A reconciliation. *J. Exp. Psychol. Learn. Mem. Cogn.* 31: 1235–1249.
Cheung H (1996) Nonword span as a unique predictor of second-language vocabulary learning. *Dev. Psychol.* 32: 867–873.
Clark HH and Clarke EV (1977) *Psychology and Language*. New York: Harcourt Brace Jovanovitch.
Colle HA and Welsh A (1976) Acoustic masking in primary memory. *J. Verb. Learn. Verb. Behav.* 15: 17–32.
Collette F and Van der Linden M (2002) Brain imaging of the central executive component of working memory. *Neurosci. Biobehav. Rev.* 26: 105–125.
Conrad R (1964) Acoustic confusion in immediate memory. *Br. J. Psychol.* 55: 75–84.
Cowan N (1995) *Attention and Memory: An Integrated Framework*. New York: Oxford University Press.
Cowan N (2001) The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behav. Brain Sci.* 24: 87.
Cowan N, Day L, Saults JS, Keller TA, Johnson T, and Flores L (1992) The role of verbal output time in the effects of word length on immediate memory. *J. Mem. Lang.* 31: 1–17.
Cowan N, Keller TA, Hulme C, Roodenrys S, McDougall S, and Rack J (1994) Verbal memory span in children: Speech timing cues to the mechanisms underlying age and word length effects. *J. Mem. Lang.* 33: 234–250.
Cowan N, Johnson TD, and Saults JS (2005) Capacity limits in list item recognition: Evidence from proactive interference. *Memory* 13: 293–299.
Craik FI, Govoni R, Naveh-Benjamin M, and Anderson ND (1996) The effects of divided attention on encoding and retrieval processes in human memory. *J. Exp. Psychol. Gen.* 125: 159–180.
Daneman M and Carpenter PA (1980) Individual differences in working memory and reading. *J. Verbal Learn. Verbal Behav.* 19: 450–466.
Daneman M and Carpenter PA (1983) Individual differences in integrating information between and within sentences. *J. Exp. Psychol. Learn. Mem. Cogn.* 9: 561–584.
Daneman M and Merikle PM (1996) Working memory and language comprehension: A meta-analysis. *Psychon. Bull. Rev.* 3: 422–433.
Della Sala S and Logie RH (2003) Neuropsychological impairments of visual and spatial working memory. In: Baddeley AD, Kopelman MD, and Wilson BA (eds.) *Handbook of Memory Disorders,* 2nd edn., pp. 271–292. New York: Wiley.
Della Sala S, Gray C, Baddeley AD, Allemano N, and Wilson L (1999) Pattern span: A tool for unwelding visuo-spatial memory. *Neuropsychologia* 37: 1189–1199.
Engle RW, Cantor J, and Carullo JJ (1992) Individual differences in working memory and comprehension: A test of four hypotheses. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 972–992.
Engle RW, Kane MJ, and Tuholski SW (1999a) Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In: Miyake A and Shah P (eds.) *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*, pp. 102–134. New York: Cambridge Univ. Press.
Engle RW, Tuholski SW, Laughlin JE, and Conway ARA (1999b) Working memory, short-term memory, and general fluid intelligence: A latent variable approach. *J. Exp. Psychol. Gen.* 125: 309–331.
Flavell JH, Beach DR, and Chinsky JM (1966) Spontaneous verbal rehearsal in a memory task as a function of age. *Child Dev.* 37: 283–299.
Gathercole SE (1999) Cognitive approaches to the development of short-term memory. *Trends Cogn. Sci.* 3: 410–418.
Gathercole SE (2004) Working memory and learning during the school years. *Proc. Br. Acad.* 125: 365–380.
Gathercole SE (2006) Nonword repetition and word learning: The nature of the relationship. *Appl. Psycholing.* 27: 513–543.
Gathercole SE and Alloway TP (in press) *Working Memory and Learning: A Teacher's Guide.* Thousand Oaks, CA: Sage Publications.
Gathercole SE and Baddeley AD (1989) Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. *J. Mem. Lang.* 28: 200–213.
Gathercole SE and Baddeley AD (1990a) The role of phonological memory in vocabulary acquisition: A study of young children learning new names. *Br. J. Psychol.* 81: 439–454.
Gathercole S and Baddeley A (1990b) Phonological memory deficits in language disordered children: Is there a causal connection? *J. Mem. Lang.* 29: 336–360.
Gathercole SE and Baddeley AD (1993) *Working Memory and Language*. Hove, UK: Lawrence Erlbaum.
Gathercole SE and Hitch G (1993) The development of rehearsal: A revised working memory perspective. In: Collins A,

Gathercole S, Conway M, and Morris P (eds.) *Theories of Memory*. Hove, UK: Lawrence Erlbaum Associates.
Gathercole SE, Adams A-M, and Hitch GJ (1994a) Do young children rehearse? An individual-differences analysis. *Mem. Cogn.* 22: 201–207.
Gathercole SE, Willis C, Emslie H, and Baddeley AD (1994b) The Children's Test of Nonword Repetition: A test of phonological working memory. *Memory* 2: 103–127.
Gathercole SE, Hitch GJ, Service E, and Martin AJ (1997) Short-term memory and new word learning in children. *Dev. Psychol.* 33: 966–979.
Gathercole SE, Pickering SJ, Ambridge B, and Wearing H (2004a) The structure of working memory from 4 to 15 years of age. *Dev. Psychol.* 40: 177–190.
Gathercole SE, Pickering SJ, Knight, and Stedmann (2004b) Working memory skills and educational attainment: Evidence from national curriculum assessments at 7 and 14 years of age. *Appl. Cogn. Psychol.* 18: 1–16.
Gathercole SE, Alloway TP, Willis CS, and Adams AM (2006a) Working memory in children with reading disabilities. *J. Exp. Child Psychol.* 93: 265–281.
Gathercole SE, Lamont E, and Alloway TP (2006b) Working memory in the classroom. In: Pickering S (ed.) *Working Memory and Education*, pp. 219–240. London: Elsevier.
Geary DC, Hoard MK, Byrd-Craven J, and DeSoto MC (2004) Strategy choices in simple and complex addition: Contributions of working memory and counting knowledge for children with mathematical disability. *J. Exp. Child Psychol.* 88: 121–151.
Hanley JR, Young AW, and Pearson NA (1991) Impairment of the visuo-spatial sketchpad. *Q. J. Exp. Psychol.* 43A: 101–125.
Henson R (2005) What can functional neuroimaging tell the experimental psychologist? *Q. J. Exp. Psychol.* 58: 192–233.
Henson RNA, Norris DG, Page MPA, and Baddeley AD (1996) Unchained memory: Error patterns rule out chaining models of immediate serial recall. *Q. J. Exp. Psychol.* 49A: 80–115.
Hitch GJ and Halliday MS (1983) Working memory in children. *Philos. Trans. R. Soc. Lond. B* 302: 324–340.
Hitch GJ, Towse JN, and Hutton U (2001) What limits children's working memory span? Theoretical accounts and applications for scholastic development. *J. Exp. Psychol. Gen.* 130: 184–198.
Hulme C and Tordoff V (1989) Working memory development: The effects of speech rate, word length, and acoustic similarity on serial recall. *J. Exp. Child Psychol.* 47: 72–87.
Jarvis HL and Gathercole SE (2003) Verbal and non-verbal working memory and achievements on national curriculum tests at 11 and 14 years of age. *Educat. Child Psychol.* 20: 123–140.
Jefferies E, Lambon-Ralph MA, and Baddeley AD (2004) Automatic and controlled processing in sentence recall: The role of long-term and working memory. *J. Mem. Lang.* 51: 623–643.
Johnson RA, Johnson C, and Gray C (1987) The emergence of the word length effect in young children: The effects of overt and covert rehearsal. *Br. J. Dev. Psychol.* 5: 243–248.
Jones DM, Hughes RW, and Macken WJ (2006) Perceptual organization masquerading as phonological storage: Further support for a perceptual-gestural view of short-term memory. *J. Mem. Lang.* 54: 265–281.
Just MA and Carpenter PA (1992) A capacity theory of comprehension: Individual differences in working memory. *Psychol. Rev.* 99: 122–149.
Kane MJ, Hambrick DZ, Tuholski SW, Wilhelm O, Payne TW, and Engle RW (2004) The generality of working-memory capacity: A latent-variable approach to verbal and visuo-spatial memory span and reasoning. *J. Exp. Psychol. Gen.* 133: 189–217.
Kyllonen PC and Chrystal RE (1990) Reasoning ability (little more than) working memory capacity. *Intelligence* 14: 389–433.
Logie RH (1995) *Visuo-Spatial Working Memory*. Hove, UK: Erlbaum.
McCarthy RA and Warrington EK (1987) Understanding: A function of short-term memory? *Brain* 110: 1565–1578.
Masoura E and Gathercole SE (1999) Phonological short-term memory and foreign vocabulary learning. *Int. J. Psychol.* 34: 383–388.
Miyake A and Shah P (1999) *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*. New York: Cambridge University Press.
Muller NG and Knight RT (2006) The functional neuroanatomy of working memory: Contributions of brain lesion studies. *Neuroscience* 139: 51–58.
Murray DJ (1968) Articulation and acoustic similarity in short-term memory. *J. Exp. Psychol.* 78: 679–684.
Neath I, Farley LA, and Surprenant AM (2003) Directly assessing the relationship between irrelevant speech and articulatory suppression. *Q. J. Exp. Psychol.* 56A: 1269–1278.
Owen AM, McMillan KM, Laird AR, et al. (2005) N-back working memory paradigm: A meta-analysis of normative functional neuroimaging. *Hum. Brain Mapp.* 25: 46–59.
Page MPA and Norris D (1998) The Primacy model: A new model of immediate serial recall. *Psychol. Rev.* 105: 761–781.
Palmer S (2000) Working memory: A developmental study of phonological recoding. *Memory* 8: 179–194.
Papagno C and Vallar G (1992) Phonological short-term memory and the learning of novel words: The effects of phonological similarity and item length. *Q. J. Exp. Psychol.* 44A: 47–67.
Papagno C, Valentine T, and Baddeley AD (1991) Phonological short-term memory and foreign-language vocabulary learning. *J. Mem. Lang.* 30: 331–347.
Peterson LR and Johnson ST (1971) Some effects of minimizing articulation on short-term retention. *J. Verb. Learn. Verb. Behav.* 10: 346–354.
Phillips WA and Christie DFM (1977) Interference with visualisation. *Q. J. Exp. Psychol.* 29: 637–650.
Pickering SJ and Gathercole SE (2004) Distinctive working memory profiles in children with special educational needs. *Educat. Psychol.* 24: 393–408.
Pickering SJ, Gathercole SE, and Peaker SM (1998) Verbal and visuo-spatial short-term memory in children: Evidence for common and distinct mechanisms. *Mem. Cogn.* 26: 1117–1130.
Pickering SJ, Gathercole SE, Hall M, and Lloyd SA (2001) Development of memory for pattern and path: Further evidence for the fractionation of visuo-spatial memory. *Q. J. Exp. Psychol.* 54A: 397–420.
Postle BR, Idzikowski C, Della Sala S, and Baddeley AD (2006) The selective disruption of spatial working memory by eye movements. *Q. J. Exp. Psychol.* 59: 100–120.
Quinn JG and McConnell J (1996) Irrelevant pictures in visual working memory. *Q. J. Exp. Psychol.* 49A: 200–215.
Ransdell S and Hecht S (2003) Time and resource limits on working memory: Cross-age consistency in counting span performance. *J. Exp. Child Psychol.* 86: 303–313.
Romani C (1992) Are there distinct input and output buffers – evidence from an aphasic patient with an impaired output buffer? *Lang. Cogn. Process.* 7: 131–162.
Russell J, Jarrold C, and Henry L (1996) Working memory in children with autism and with moderate learning difficulties. *J. Child Psychol. Psychiatry* 37: 673–686.
Service E (1992) Phonology, working memory, and foreign-language learning. *Q. J. Exp. Psychol.* 45A: 21–50.

Shah P and Miyake A (1996) The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *J. Exp. Psychol. Gen.* 125: 4–27.
Shallice T (1982) Specific impairments of planning. *Philos. Trans. R. Soc. Lond. B* 298: 199–209.
Shallice T and Butterworth B (1977) Short-term memory impairment and spontaneous speech. *Neuropsychologia* 15: 729–735.
Smyth MM and Scholey KA (1996) Serial order in spatial immediate memory. *Q. J. Exp. Psychol. A.* 49: 159–177.
Surprenant AM, Neath I, and LeCompte DC (1999) Irrelevant speech, phonological similarity, and presentation modality. *Memory* 7: 405–420.
Swanson HL and Beebe-Frankenberger M (2004) The relationship between working memory and mathematical problem solving in children at risk and not at risk for math disabilities. *J. Educat. Psychol.* 96: 471–491.
Swanson HL, Ashbaker MH, and Lee C (1996) Learning-disabled readers' working memory as a function of processing demands. *J. Exp. Child Psychol.* 61: 242–275.
Thompson JM, Hamilton CJ, Gray JM, et al. (2006) Executive and visuospatial sketchpad resources in euthymic bipolar disorder: Implications for visuospatial working memory architecture. *Memory* 14: 437–451.
Towse JN and Hitch GJ (1995) Is there a relationship between task demand and storage space in tests of working memory capacity? *Q. J. Exp. Psychol.* 48: 108–124.
Towse JN, Hitch GJ, and Hutton U (1998) A reevaluation of working memory capacity in children. *J. Mem. Lang.* 39: 195–217.
Towse JN, Hitch GJ, and Hutton U (2002) On the nature of the relationship between processing activity and item retention in children. *J. Exp. Child Psychol.* 82: 156–184.
Turner MLM and Engle RW (1989) Is working memory capacity task dependent? *J. Mem. Lang.* 28: 127–154.
Unsworth N and Engle RW (2006) Simple and complex memory spans and their relation to fluid abilities: Evidence from list-length effects. *J. Mem. Lang.* 54: 68–80.
Vallar G and Baddeley AD (1984) Fractionation of working memory: Neuropsychological evidence for a short-term store. *J. Verb. Learn. Verb. Behav.* 23: 151–161.
Vallar G and Baddeley AD (1987) Phonological short-term store and sentence processing. *Cogn. Neuropsychol.* 6: 465–473.
Vallar G and Papagno C (2003) Neuropsychological impairments of short-term memory. In: Baddeley AD, Kopelman MD, and Wilson BA (eds.) *Handbook of Memory Disorders*, pp. 249–270. Chichester, UK: John Wiley.
Vallar G and Shallice T (1990) *Neuropsychological Impairments of Short-Term Memory*. Cambridge: Cambridge University Press.
Waugh NC and Norman DA (1965) Primary memory. *Psychol. Rev.* 72: 89–104.
Wheeler ME and Treisman AM (2002) Binding in short-term visual memory. *J. Exp. Psychol. Gen.* 131: 48–64.
Wilson JTL, Scott JH, and Power KG (1987) Developmental differences in the span of visual memory for pattern. *Br. J. Dev. Psychol.* 5: 249–255.

# 2.05 Serial Learning

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In many activities in everyday life, we are required to learn the serial order of a set of elements. For example, whenever we acquire a new word, we must learn a novel order of sounds. As Lashley (1951) pointed out in his classic paper, the problem of learning serial order is that elementary movements occur in many different orders in different actions. How, then, can an individual who knows the elementary movements in an action learn to produce them in the correct sequence? For example, how can a pianist who knows the notes occurring in a given song learn to produce the notes in the correct order? That is the central problem involved in serial learning.

## 2.05.1 Concepts

To address this problem, we need to define several important concepts and make some crucial distinctions: Performing a serial task requires subjects to display knowledge of both the elements in the task and their arrangement. The task elements are items, and their arrangement is their order. In discussing serial learning, order is usually based on the temporal sequence in which the items occur, but in some cases order is based instead on the spatial locations of the items. Thus, letters are the items in words, and the letters must appear in a fixed order for a given word to be identified. The words 'tap' and 'pat' have the same items, but their different orders create different meanings. We can describe the order of the items either in terms of their ordinal positions without reference to their relational sequence (in 'tap,' 't' is first, 'a' is second, and 'p' is third) or in terms of their relational sequence without reference to their ordinal positions (in 'tap,' 't' precedes 'a' and 'p' follows 'a').

In cognitive psychology, learning typically refers to the process of acquiring information over time, whereas memory usually refers to the retention (or forgetting) of information. Thus, in the study of serial learning, we are most concerned with the acquisition of order information, but we also need to understand the underlying memory processes that provide the foundation for such learning over time. In practice, assessments of learning typically involve multiple study and test episodes, but assessments of memory usually involve a single study episode followed by a single test. Thus, memory research can be viewed as providing a snapshot of the first stage of the learning process.

## 2.05.2 Tasks

The original procedure used to investigate serial learning was established by Ebbinghaus (1885/1913).

In this repeated study–test procedure, a list of items is studied and then tested by requiring recall of the items in the order in which they were shown. This procedure is repeated until the subject reaches a criterion of recalling the list without error. Later researchers replaced this procedure with the method of anticipation, in which subjects are shown one item for a fixed amount of time and are then required to anticipate the next item in the sequence. Subsequently, the next item is shown, which provides feedback to subjects as to the correctness of their last response. This procedure continues throughout the presentation of a list, and list presentation is repeated until the subject reaches a criterion, perhaps one time through the list without error. The investigator tabulates how many presentations of the list are required to reach the criterion.

In recent investigations, the focus has shifted from the learning of order information to immediate memory for order information. Consequently, the most popular procedure is that of serial recall. In this case, subjects are given a series of items to study and are then required to recall the entire list in sequential order. Serial recall can be contrasted with free recall, in which subjects are free to report the items in any order they want and do not need to indicate the sequence information in any way. In serial recall tasks, subjects learn multiple different lists rather than the same list repeatedly. Often the investigator includes a delay between the presentations of successive items (interitem interval) or between the presentation of the last item on the list and the recall test (retention interval). Sometimes extraneous distracting items are interpolated during either the interitem interval or the retention interval to prevent subjects from rehearsing (practicing) the items during those intervals.

In the recall procedures, to respond correctly, subjects must remember the items. Another method was developed to isolate memory for order even further by eliminating the need for the subjects to remember the items. Specifically, the items are given to the subjects either in advance or during the trial, and the subjects simply have to reconstruct the order in which the items occurred. For example, for the list ABCDEF the subjects might be told that the items were BFACED, and they would have to rearrange the items into the correct sequence by placing A into the first slot, B into the second slot, and so on. In reconstructing the order, the subjects thus place each item into its appropriate position, perhaps in a horizontal array of slots, but the slots do not necessarily have to be filled in order from left to right. If a left-to-right response is required, the task is serial reconstruction of order, whereas if no constraints on response order are specified, the task is free reconstruction of order, using the same distinction described earlier for serial and free recall.

A new repeated study–test procedure has been developed to investigate both memory for and learning of serial lists, with successive snapshots of the learning process taken until a criterion is reached (Bonk, 2006). This procedure can be viewed as a combination of three common tasks already described: serial learning, serial recall, and serial reconstruction of order. Under this procedure, subjects view a display showing a set of items including both targets and distractors. The targets are then highlighted one at a time to indicate the required sequence. Subjects observe this presentation and then reconstruct the sequence by choosing one item at a time. The items can vary in type, but in the initial study were clip art pictures. The sequences can vary in length, and in the initial study they were from 6 to 15 items long. To respond correctly, subjects must remember both the identity of the target items and the order in which they occurred. A given sequence of target items is shown and recalled multiple times until the subject reaches the criterion of two perfectly recalled sequences in a row.

## 2.05.3 Results

The most widely cited experimental result in the study of serial order is the serial position function, first described by Nipher (1878; see also Stigler, 1978) for serial recall. To obtain this function, every position in the list is scored separately, and the total number of correct responses at a given position is computed either across repetitions of the list (in a learning paradigm such as the method of anticipation) or across different lists (in a memory paradigm such as serial recall). The function typically takes on a bow shape (like a bow in archery), wherein items at the start and end of the list are remembered better than intermediate items. The advantage for the initial items is the primacy effect, and the advantage for the final items is the recency effect. In serial learning, the primacy advantage is typically much larger and includes more items than the recency advantage, which sometimes includes only a single item. Asymmetrical bow-shaped functions for the initial test of a given list in the new repeated study–test procedure developed by Bonk (2006) are shown in **Figure 1** for each of 10 list lengths. Asymmetrical

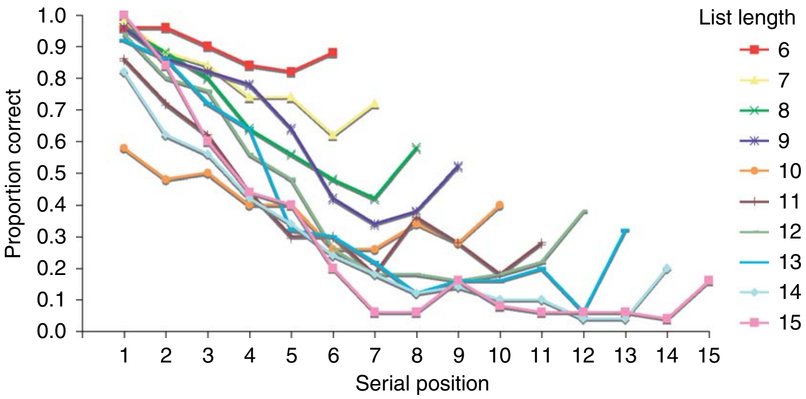


**Figure 1** Mean proportion of correct responses as a function of list length and serial position for initial tests in serial learning experiment by Bonk (2006).

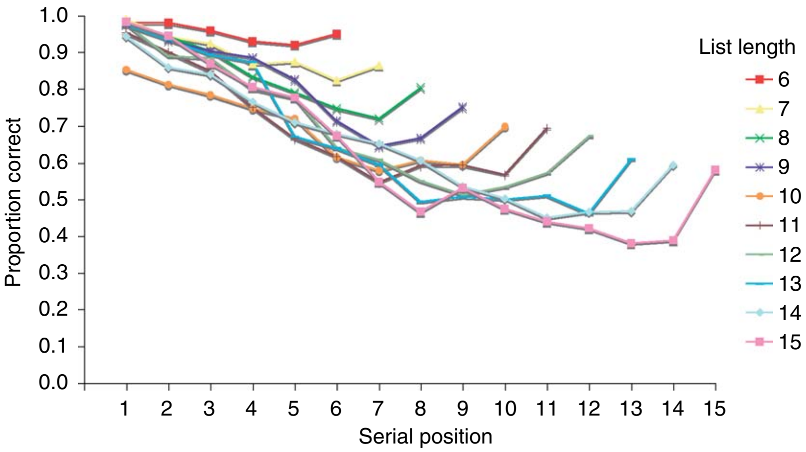


**Figure 2** Mean proportion of correct responses as a function of list length and serial position for all attempts through the first perfect recall of a given list by a given subject in serial learning experiment by Bonk (2006).

bow-shaped functions are shown in **Figure 2** for all tests of a given list through the first perfect recall, again for the same 10 list lengths. **Figure 1**, thus, shows curves reflecting serial recall, whereas **Figure 2** shows curves reflecting serial learning. The curves are different, but both show an asymmetrical bow shape. Although the level of performance in serial recall or serial learning may depend on many factors, such as the rate at which the items are presented or the familiarity of the items, the serial position curve typically takes on the same shape when it is normalized. Normalization requires computing the proportion of all correct responses that occur at each serial position of a given list by a given subject. For example, if a subject on a six-item list took three attempts to reach the criterion and during those attempts made a total of 15 correct responses, with 3 of them on the first serial position, the normalized proportion correct for that position would be $3/15 = 0.20$. The fact that the shape of the normalized serial position function is constant across serial learning conditions was first demonstrated by McCrary and Hunter (1953). The normalized functions for the serial learning results of Bonk (2006) are shown in **Figure 3**, again for all 10 list lengths.

Other widely studied results involve the errors made by subjects in tasks requiring serial order. A frequent type of error is one in which the correct item is given but is not placed into its correct position. In a serial recall task, this is a transposition error. Typically, transposition errors occur in pairs because the positions of two adjacent items are confused. For example, if subjects are given the list ABCDEF and they recall ACBDEF, they have transposed a pair of

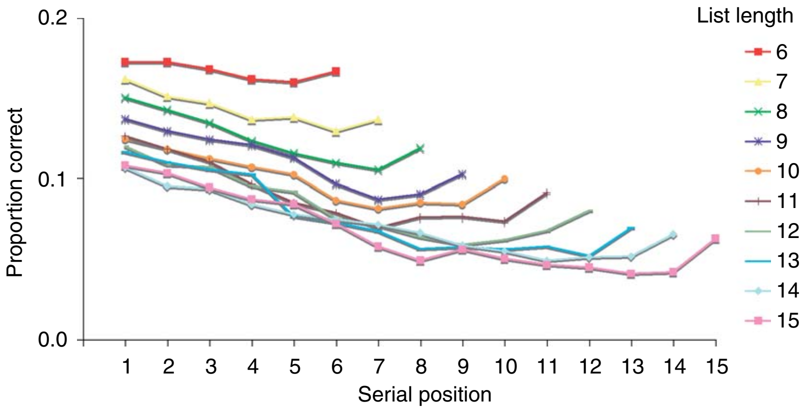


**Figure 3** Mean normalized proportion of correct responses as a function of list length and serial position for all attempts through the first perfect recall of a given list by a given subject in serial learning experiment by Bonk (2006).

letters, B and C. Such a paired transposition would result in errors at two of the six list positions, positions 2 and 3. A nontransposition error is any other type of error in this task, such as when an item that did not occur in the list is substituted for a correct letter. For example, if subjects respond with YBCDEZ to the sample list, they have made nontransposition errors at two of the six list positions, positions 1 and 6.

Even with shorter lists, a bow-shaped serial position function is found for serial recall. In a procedure known as the distractor paradigm, items are briefly presented, followed by a retention interval filled with an interpolated task, often consisting of items of a different type, all of which must be read aloud by the subjects. For example, a list of four letters might be presented followed by a variable number of digits, with subjects reading aloud both the letters and digits before they recall the letters in the order shown. This procedure allows the investigators to examine the amount of information remaining in memory after various delays when rehearsal of the information is prevented. Using this procedure and differentiating between transposition and nontransposition errors, Bjork and Healy (1974) found that symmetrical bow-shaped serial position functions were found for total errors at each of three different retention intervals (3, 8, or 18 interpolated digits). These functions, when decomposed into transposition and nontransposition errors, showed a bow shape only for the transposition errors; the functions for nontransposition errors were much flatter, as shown in **Figure 4**.

Transposition errors can be further described in terms of a positional uncertainty gradient, which is a function of the distance between the input positions of the correct item and the item that substitutes for it in the subject's recall response. When the distance is short, the probability of an error is typically larger than when the distance is long. Such error gradients are shown in **Figure 5** for two different conditions in which order information was isolated by telling the subjects in advance which items would occur and using the same set of items on every trial of the experiment (Healy, 1975). The list items occurred one at a time in different spatial locations arranged in a row, with the spatial and temporal positions independently manipulated. In the temporal condition, the items occurred in fixed spatial locations, so only the temporal sequence of the items needed to be learned and remembered. In the spatial condition, the items occurred in a fixed temporal sequence, so only the spatial locations of the items needed to be learned and remembered. The items in this experiment were four consonant letters in each condition. As in the experiment by Bjork and Healy (1974), there were three different retention intervals, with 3, 8, or 18 interpolated digits. These functions show three striking differences in the retention of temporal and spatial order information. First, the decline in accuracy across retention intervals is sharp in the temporal condition but modest in the spatial condition. Second, the serial position function (evident by examining correct responses) is bow-shaped in the temporal condition but not in the spatial condition. Third, the error gradients are steeper in the temporal condition than in the spatial condition.

One specific type of nontransposition error that often occurs is a confusion error, in which a given item is replaced with another item that is confusable

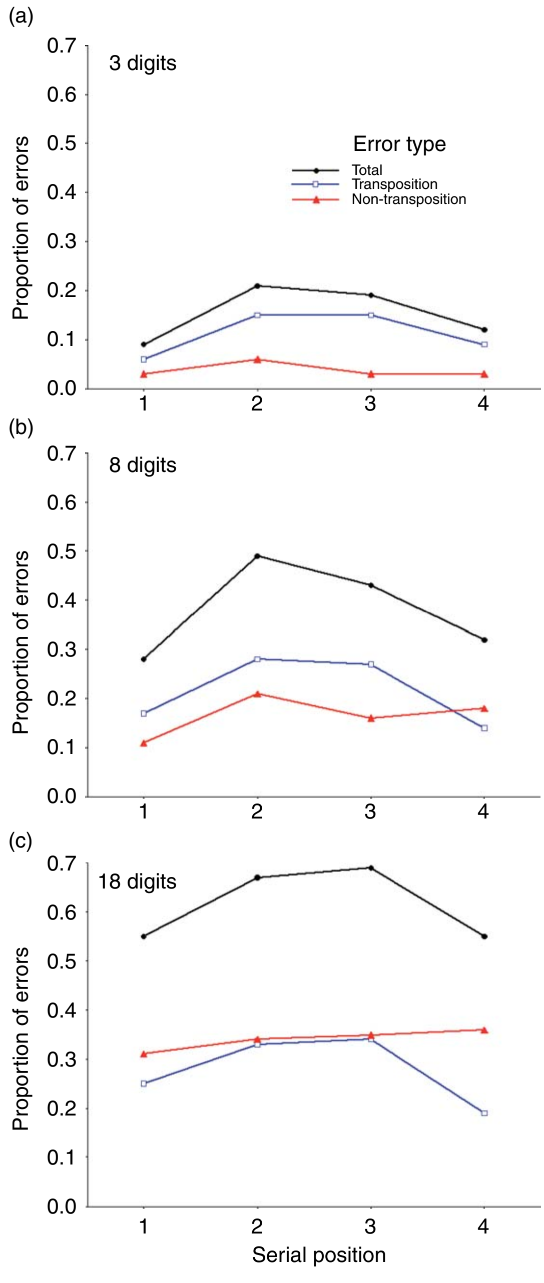


**Figure 4** Mean proportion of errors as a function of retention interval (i.e., for 3, 8, and 18 interpolated digits), and serial position for all errors (total) and separately for transposition and nontransposition errors in serial recall experiment by Bjork and Healy (1974).

with it. In our example, a confusion error would occur in the second position if subjects respond with AGCDEF. The confusion error is presumably a result of similarity between the original item and the one replacing it, such as the similarity in sound between the letters B and G in the example. Such an error could be classified as a phonological confusion error. Other types of confusion errors are also possible. For example, if the items were words, the confusions could be based on similarity of meaning rather than sound, in which case they would be semantic confusion errors (e.g., replacing 'cot' with 'bed').

Often a nontransposition error is not based on item similarity but, rather, on positional similarity. Specifically, subjects show a tendency to replace an item in a given list with an item from the same position in an earlier list (e.g., Conrad, 1960; Estes, 1991). For example, if subjects see the list ABCDEF followed by the list GHIJKL and they recall the second list as GHIJEL, they have replaced the item in the fifth position of the second list with the item in the same position of the previous list. This type of error is a serial order intrusion.

Both the serial position functions and the different types of errors give us clues that help us understand the cognitive processes underlying memory for and learning of serial order information.

## 2.05.4 Theories

### 2.05.4.1 Classic Theories

The classic theories are largely theories of serial learning because the most popular experimental paradigm used at the time they were developed was the method of anticipation, and this paradigm provided the data that were to be explained by the models.

#### *2.05.4.1.1 Associative chaining*

An early description of serial learning was based on an associative chaining model wherein one item in a sequence was linked to (associated with) the next item in a chain (see, e.g., Crowder, 1968). This model was a natural outgrowth of the serial learning task involving the method of anticipation in which each item in the list is explicitly given as a cue for the next item. In our example of the list ABCDEF, the letter A would be linked to the letter B, B to C, and so on. However, even for that task, the simple associative chaining model may not be appropriate, as is evident intuitively from the observation that missing one item in a serial list does not lead to failure to report all subsequent list items. For example, a chaining model may predict that, in memorizing a complete poem, if any word is forgotten then it would be impossible to recall subsequent words in the poem. This particular problem is overcome if there are associative links of

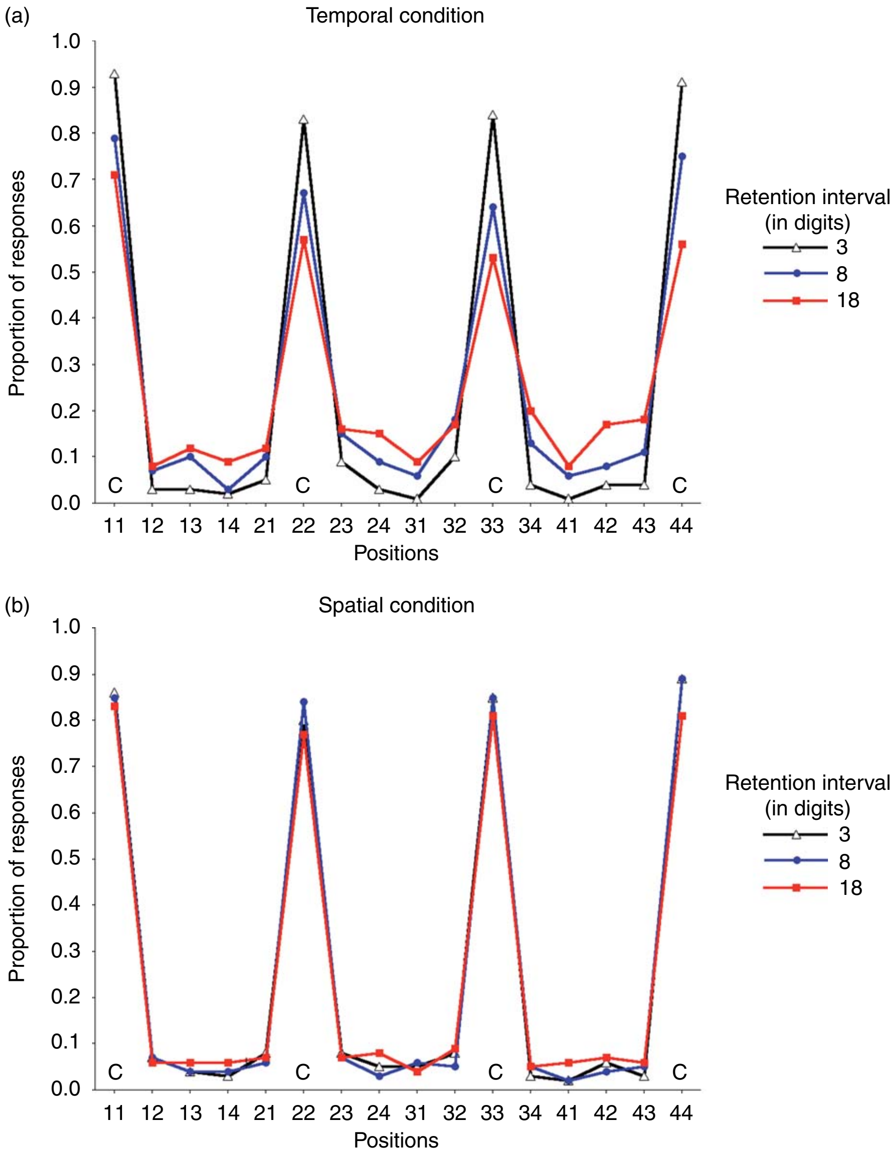


**Figure 5** Mean positional uncertainty gradients for temporal and spatial conditions of experiment by Healy (1975). The point plotted for position ij represents the proportion of instances in which the response occurring at position i was the item appearing in input position j of the trial. The label C indicates correct responses.

varying strength among all items in the list, not just neighboring items, with the associations for adjacent items stronger than the more remote associations linking items that are not adjacent in the list. Thus, if a word in a poem is forgotten, subsequent words could still be recalled on the basis of remote associations from earlier words in the poem that could serve as cues. However, even such compound chaining could not overcome other types of evidence against this class of models. For example, in one experiment using the method of anticipation, subjects learned a serial list of adjectives to a criterion of one perfect trial. Then they were given a task to learn a set of paired associates, with experimental pairs formed from adjacent adjectives in the previous list and control pairs formed from unrelated adjectives. Subjects learned the experimental pairs no faster than they learned the control pairs in the paired associate task (Young, 1962), which seems inconsistent with the assumption that in the serial learning task subjects formed strong associations between adjacent items (but see Crowder, 1968, for counterevidence supporting the existence of such associations).

#### 2.05.4.1.2 Positional coding

Another early description of serial learning is also based on associations between stimuli and responses; it involves a simple positional coding model. In this case, the associations are not from one item to the next but, rather, between a given item and its ordinal position (see, e.g., Young et al., 1967). In our example, the letter A would be associated with ordinal position 1, B would be associated with ordinal position 2, and so on. One version of this theory is a box model (Conrad, 1965), according to which each successive item in a list is entered into a box, with the boxes preordered in memory. Item information in the boxes gets degraded with the passage of time, and at recall subjects output items for each box in turn using whatever information is still available. Transposition errors occur in this model not because of a reordering of the boxes but, rather, because information about an item in a given box is degraded so that the remaining partial information may be consistent with another list item, leading to report of that other item rather than the correct one for that position. This simple model was also refuted by experiments testing it. For example, in a study like the earlier one testing the chaining model, subjects learned, using the method of anticipation, an ordered list of adjectives to a criterion of one perfect trial. Then they were given a task to learn a set of paired associates, in this case with the ordinal position numbers as stimuli and the serial list adjectives as responses. Subjects did not perform as well on the paired associate task, at least on the intermediate items, as they should have if they had in effect learned those associations previously during the serial learning task (Young et al., 1967).

#### 2.05.4.1.3 Positional distinctiveness

A simple but powerful model was proposed by Murdock (1960) to account for the serial position function in serial learning solely in terms of the distinctiveness of the positions. By this model, a given position's distinctiveness is determined merely by comparing its ordinal position value to the values of all of the other list positions. For example, in a five-item list, the difference between the ordinal position value for the first position and the value for the other positions is the sum of $|1-2|$, $|1-3|$, $|1-4|$, and $|1-5|$, which is $1+2+3+4=10$. In contrast, a similar calculation for the third position yields $|3-1|$, $|3-2|$, $|3-4|$, and $|3-5|$, which is $2+1+1+2=6$. Thus, as is also clear intuitively, the first position is more different from the other positions than is the third position. The actual calculation of distinctiveness is a bit more complex because log values are used instead of the ordinal numbers themselves. The use of log values allows the model to account for the finding that primacy effects are typically stronger than recency effects. According to this model, the serial position function should be the same shape for all lists of a given length, even if the lists vary in terms of their presentation time or the familiarity of the items that comprise them. Indeed, as mentioned earlier, normalized serial position functions have the same shape across all experimental conditions (McCrary and Hunter, 1953).

### 2.05.4.2 Contemporary Theories

Unlike the classic theories, contemporary theories are largely theories of immediate serial memory because the most popular experimental methodology became the immediate serial recall paradigm, and this paradigm provided much of the data that were to be explained by the theories. Thus, the emphasis has shifted from the learning of serial order information to immediate memory for serial order information. The new data by Bonk (2006), which examine serial recall on successive learning trials, provides an empirical integration of serial memory and serial learning results, but little theoretical integration has yet been proposed.

#### 2.05.4.2.1 Perturbation model

An elegant model was proposed by Estes (1972) to account for serial recall performance in the distractor paradigm. Like the classic models, the perturbation model is based on simple associations. However, the associations in this case are between an individual list item and a control element, which represents the given context or environment in which the list was learned. At the core of the model is the concept of a reverberating loop that links the control element to a given list item, with a recurrent reactivation of the list item each time the control element is accessed. Because all the items in a list are associated to the same control element, the difference in reactivation times reflects their input order. The timing of the reactivations, thus, provides the basis for knowledge of the order of the items in a list. This knowledge is assumed to be perfectly stored in memory immediately after the list is presented. Loss of such information, resulting in failure to recall the items in the correct order, may then occur for one of two reasons. First, the subject may lose access to the control element, perhaps because the experimental context has shifted as a function of time or because of some interpolated, interfering activity. Second, there may be perturbations, or disturbances, in the timing of the recurrent reactivations, presumably resulting from random neural activity. If the timing perturbations are large enough, two adjacent list items may be interchanged so that the later item is reactivated before the earlier item, thus leading to transposition errors in recall. The perturbation process can account for the symmetrical bow-shaped serial position functions found in immediate serial recall of short lists because the likelihood of interchanges resulting from timing perturbations is greater for intermediate list items (which have neighboring items on both sides) than for end items (which have a neighboring item on only one side). This same mechanism easily accounts for the positional uncertainty gradients observed for temporal (but not spatial) order recall, wherein the likelihood of a transposition error decreases as the distance in time increases between the input positions of the correct item and the one replacing it.

After its original formulation, the perturbation model was refined to account for the fact that order information can be viewed as hierarchical (Lee and Estes, 1981). If lists are divided into subsets, perhaps by adding pauses between groups of items, then subjects need to know on which list a given item occurred and in which subset of the list it occurred, as well as its relative position in the subset. According to the refined version of the perturbation model, each item is coded for its placement in this three-tier hierarchy. The hierarchy of codes is repeatedly reactivated, and the perturbation process applies independently at each level, so at each reactivation there is a probability that the relative position of adjacent lists, subsets, or items will be disturbed. This hierarchical perturbation process produces serial order intrusion errors, when an item in a given list or list subset is replaced by an item from the same position in an earlier list or list subset.

#### *2.05.4.2.2 Start-end model*

The start-end model (Henson, 1998) was proposed to account for the serial position functions, the positional uncertainty gradients, and the distributions of different types of errors in the serial recall task. At the heart of this model is the observation that the start and end of a list are most salient and therefore serve as anchors, or markers, to code for each item's position in the list (see Feigenbaum and Simon, 1962, for an earlier use of the notion of list end items serving as anchors). Each item gets a two-value code based on the strength of both the start and end markers at that point in the list. The start marker is assumed to be strongest at the beginning of the list and to get progressively weaker for subsequent list items. In contrast, the end marker is assumed to be weakest at the beginning of the list and to get progressively stronger for subsequent list items. Although the end is not evident at the start of the list, subjects anticipate the end (at least when they know the list length), and that expectation allows for the use of the end marker. The model reproduces the general finding that primacy effects are larger than recency effects by giving greater strength to the start marker than to the end marker.

This model makes use of a distinction between types and tokens as a way of representing items. A given item, such as a word, may occur in multiple lists or on multiple occasions in a given list. Each time the word occurs, the item is the same type, but the different instances of the word constitute different tokens. In the start-end model it is assumed that each item token codes both identity and positional information. The identity information specifies the content of that item (e.g., which word has occurred). The positional information is derived from the strength of the start and end markers for that item token. According to the model, the item tokens are unordered in memory; instead, they are ordered at the time of recall. Specifically, at recall the position of a given item is cued by its start and end marker strength values; the identity of the item that matches the cued strength values most closely is recovered and then recalled at that position. Another assumption made by the model is that once an item is recalled, its type is suppressed so that subjects will be less likely to recall a given item type more than once in a trial. This aspect of the model allows it to account for the Ranschburg effect (e.g., Jahnke, 1969), whereby subjects are likely to fail to recall second occurrences of a given item.

#### *2.05.4.2.3 Primacy model*

The primacy model (Page and Norris, 1998) is related to both the perturbation and start-end models but was formulated to account for a different set of results. The results in this case are those that formed the basis of Baddeley and Hitch's (1974) model of the phonological loop, which is a qualitative description of working memory that describes rehearsal processes but does not provide any specific mechanisms for serial recall. Thus, the primacy model can be viewed as a computational version of the phonological loop model (see also Burgess and Hitch, 1999, for an alternative quantitative version of this model). The primacy model does not specifically code position information, but such information is derived at the time of recall from the relative activation strengths of list items. These activation strengths vary as a function of the time when the list items occurred, forming a primacy gradient, with the strength greatest for the first item and declining for successive items in the list. These activation strengths can be thought of as reflecting the degree to which the context defining the start of the list is associated with each successive list item. By this view, the start-of-the-list context resembles both the control element of the perturbation model and the start marker of the start-end model. However, unlike the start-end model, there is no corresponding end marker in the primacy model.

To model the recall process, the primacy model implements the assumption that in a repeating cycle, the item with the greatest activation is selected for recall, and after it is recalled, it is suppressed. Subsequently, the item with the next highest activation is recalled and then suppressed, and so on. During the recall process, the activations for all list items decay exponentially with time. Errors result from the fact that there is noise in the process of selecting the item with the strongest activation (which can be viewed as noise in the perception of the activation strengths), even though there is no noise in the activation strengths themselves. Primacy effects fall out of the model naturally because of the primacy gradient, but recency effects occur because end items can only participate in a paired transposition error in one direction (i.e., with one neighbor), whereas intermediate items can participate in paired transposition errors in both directions (i.e., with neighbors on both sides). Paired transposition errors occur in this model whenever the perceived activation strength of a given list item is either less than the perceived activation strength of a subsequent list item or greater than the perceived activation strength of a preceding list item. Such paired transposition errors also rely on a property of the model called fill in, which is the assumption that when an item is missed in recall because of a transposition it is likely to be recalled in the next position. This model is, thus, consistent with the observation from Bjork and Healy (1974) that transposition errors show a bowed serial position function but nontransposition errors do not. Nontransposition errors typically increase as a function of serial position. To account for this finding, the primacy model assumes that once the item with the strongest perceived activation is selected, the activation is compared to a threshold value. If the activation is above threshold, the item will be recalled, whereas if it is below threshold, it will be omitted and the subject will resort instead to guessing an item, with this threshold comparison subject to noise. Thus, the primacy model can account for nontransposition errors as well as transposition errors.

#### 2.05.4.2.4 OSCAR

A novel approach to explaining serial recall was taken by Brown et al. (2000) in their oscillator-based computational model OSCAR. Oscillators are timing mechanisms that generate continuously changing rhythmic output. Oscillators occur at different frequencies, with high-frequency oscillators repeating more often than low-frequency oscillators. An analogy can be made to the hands in a clock face. The second hand completes its cycle more rapidly than the minute hand, which in turn completes its cycle more rapidly than the hour hand. OSCAR accounts for the learning of order by making use of oscillator timing mechanisms presumed to occur naturally in the mind. In OSCAR, during list presentation, associations are formed between a vector (an ordered series of numbers) representing a list item and a vector representing successive states of the learning context. The learning context is the current state of the dynamically changing internal set of timing oscillators. Thus, OSCAR, like other models, makes use of associations between items and a representation of the learning context. However, in OSCAR, unlike other models, the learning context changes continuously during list presentation. Just as Lee and Estes (1981) postulated a hierarchy of codes in the perturbation model, the oscillators in OSCAR vibrate at different rates, reflecting different levels of a three-tier hierarchy, including item position within a subset, subset position within a list, and list position within a session. Unlike the perturbation model, however, order errors arise in OSCAR solely during the retrieval stage. Specifically, at the time of retrieval, a sequence is recalled by reinstating the states of the set of oscillators that comprise the learning context. Each successive learning context vector is used as a probe recovering the list item vector that is associated with it. Retrieval errors occur based on the quality of the learning context vector and the extent to which that vector is specific to a particular item. Items occurring close together in time have similar learning context vector values; thus, noise in the retrieval process leads to positional uncertainty gradients like those found for the temporal condition in the study by Healy (1975). This model, unlike some of the others, can thereby explain observed differences between recall of temporal and recall of spatial order information.

#### 2.05.4.2.5 TODAM

Unlike the other contemporary theories reviewed here, which are restricted to memory for serial order, a model by Lewandowsky and Murdock (1989) is designed to account for serial learning as well as serial recall. This theory of distributed associative memory (TODAM) also differs from the other contemporary models in being based on associative chaining. Although, as mentioned earlier, problems had been found for the classic associative chaining model, these were largely overcome in TODAM. A third difference between TODAM and the other models reviewed here is that TODAM provides a more general account of memory, not being restricted to serial order (see Anderson et al., 1998, for another general model incorporating serial recall). A fourth difference is that the memory representations in TODAM are not localized but are, rather, distributed.

Specifically, in TODAM the representations of all list items are stored together in a common memory vector. The numbers making up the memory vector in TODAM represent values of individual features. Successive items are associated using a mathematical operation convolution that blends the constituent item vectors. The resulting convolution is also added to the common memory vector. If all information is contained in a single memory vector, how can the model recover the individual list items when needed? The retrieval mechanism used for this purpose is correlation, which is the inverse of convolution (i.e., it essentially undoes that operation). Thus, a memory probe representing a particular stimulus item can be correlated with the common memory vector to yield another vector that approximates the response item with which it had been associated. Once the approximation to the response item is generated via the correlation process, it must be deblurred (interpreted) before it can be recalled. If the deblurring process yields an overt recall response, the new vector resulting from that response can then be used as a stimulus probe to recover the next item in the list. The deblurring process might not result in an actual overt response. Nevertheless, the recall process can move forward to the next item in the list because the vector approximation can be used as a stimulus for a subsequent response. This implementation allows TODAM to overcome one of the key problems mentioned earlier plaguing the classic chaining model, namely, that missing one item in a serial list does not lead to failure to report all subsequent items. A subsequent version of TODAM (Murdock, 1995) also uses associations between higher-order chunks of items to avoid problems with simple associative chaining models.

To model serial learning occurring across repeated presentations of the same list, in a closed-loop variant of TODAM, the new information added to the memory vector for an item is reduced by the amount of information already present in the vector. This aspect of the model captures the idea that gradually less is learned about each item during successive repetitions of a list.

## 2.05.5 Theoretical Issues and Conclusions

A variety of theoretical mechanisms have been proposed to account for serial memory and learning, but there is little consensus as to which is the best. The various models differ along numerous important dimensions, such as the relation between item and order information and whether or not position or sequence information is explicitly coded. Some models do not discriminate between temporal and spatial order, whereas others apply only to temporal order. Crucially, most models do not attempt to provide a theoretical integration of serial memory and serial learning results. Thus, despite the theoretical insights and innovations in the five decades since Lashley (1951) first discussed the importance of this problem, we have not yet achieved a full and widely accepted understanding of the processes underlying serial order behavior, which provides the foundation for many activities in everyday life.

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## References

Anderson JR, Bothell D, Lebiere C, and Matessa M (1998) An integrated theory of list memory. *J. Mem. Lang.* 38: 341–380.
Baddeley AD and Hitch GJ (1974) Working memory. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 8, pp. 47–89. San Diego, CA: Academic Press.
Bjork EL and Healy AF (1974) Short-term order and item retention. *J. Verb. Learn. Verb. Be.* 13: 80–97.
Bonk WJ (2006) Sequence memory with visual item, spatial, and order information. Paper presented at the 76th annual convention of the Rocky Mountain Psychological Association, Park City, UT.
Brown GDA, Preece T, and Hulme C (2000) Oscillator-based memory for serial order. *Psychol. Rev.* 107: 127–181.
Burgess N and Hitch GJ (1999) Memory for serial order: A network model of the phonological loop and its timing. *Psychol. Rev.* 106: 551–581.
Conrad R (1960) Serial order intrusions in immediate memory. *Brit. J. Psychol.* 51: 45–48.
Conrad R (1965) Order error in immediate recall of sequences. *J. Verb. Learn. Verb. Be.* 4: 161–169.
Crowder RG (1968) Evidence for the chaining hypothesis of serial verbal learning. *J. Exp. Psychol.* 76: 497–500.
Ebbinghaus H (1913) Memory: A Contribution to Experimental Psychology (trans. Ruger HE and Bussenius CE). *New York: Teachers College*. (Translated from the 1885 German original.)
Estes WK (1972) An associative basis for coding and organization in memory. In: Melton AW and Martin E (eds.) *Coding Processes in Human Memory*, pp. 161–190. Washington, DC: V. H. Winston.
Estes WK (1991) On types of item coding and sources of recall in short-term memory. In: Hockley WE and Lewandowsky S (eds.) *Relating Theory and Data: Essays on Human Memory in Honor of Bennet B. Murdock*, pp. 155–173. Hillsdale, NJ: Erlbaum.
Feigenbaum EA and Simon HA (1962) A theory of the serial position effect. *Brit. J. Psychol.* 53: 307–320.
Healy AF (1975) Coding of temporal-spatial patterns in short-term memory. *J. Verb. Learn. Verb. Be.* 14: 481–495.
Henson RNA (1998) Short-term memory for serial order: The start-end model. *Cognitive Psychol.* 36: 73–137.
Jahnke JC (1969) The Ranschburg effect. *Psychol. Rev.* 76: 592–605.
Lashley KS (1951) The problem of serial order in behavior. In: Jeffress LA (ed.) *Cerebral Mechanisms in Behavior*, pp. 112–146. New York: Wiley.
Lee CL and Estes WK (1981) Item and order information in short-term memory: Evidence for multilevel perturbation processes. *J. Exp. Psychol-Hum. L.* 7: 149–169.
Lewandowsky S and Murdock BB, Jr. (1989) Memory for serial order. *Psychol. Rev.* 96: 25–57.
McCrary J and Hunter WS (1953) Serial position curves in verbal learning. *Science* 117: 131–134.
Murdock BB Jr. (1960) The distinctiveness of stimuli. *Psychol. Rev.* 67: 16–31.
Murdock BB (1995) Developing TODAM: Three models for serial-order information. *Mem. Cognition* 23: 631–645.
Nipher FE (1878) On the distribution of errors in numbers written from memory. *Transactions of the Academy of Science of St. Louis* 3: ccx–ccxi.
Page MPA and Norris D (1998) The primacy model: A new model of immediate serial recall. *Psychol. Rev.* 105: 761–781.
Stigler SM (1978) Some forgotten work on memory. *J. Exp. Psychol-Hum. L.* 4: 1–4.
Young RK (1962) Tests of three hypotheses about the effective stimulus in serial learning. *J. Exp. Psychol.* 63: 307–313.
Young RK, Hakes DT, and Hicks RY (1967) Ordinal position number as a cue in serial learning. *J. Exp. Psychol.* 73: 427–438.

# 2.06 Repetition and Spacing Effects

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Coyne (2006) dedicated himself to becoming as good a golfer as he could possibly be. He spent a year in this quest, hitting more than 100 000 golf balls and playing 5418 holes. He found that practice at this skill indeed led to improvement but was frustrated to find out that not all practice was equally effective. The beginning of his regimen led to the fastest improvement, an observation that led Coyne to compare his situation to that of a dieter finding that the first few pounds lost were the easiest. Coyne's observations are typical, as the importance, as well as the limitations, of repetition in the mastery of information or skill can be documented in countless domains (Ericsson, 2005).

That repetition is key to learning but that not all repetitions are equally effective are central observations underlying all serious thought on the topic. The central importance of repetition was recognized by many ancient and medieval thinkers. Hermann Ebbinghaus (1885/1964), who initiated the modern era of memory research, carried out a series of experiments that showed that retention improved as a function of the number of times that information had been studied. Ebbinghaus's theoretical approach assumed the centrality of repetition in the acquisition and strengthening of learning.

The fact that learning and memory are sensitive to repetition is not in question. However, the basis of repetition effects is still far from clear. Boundary conditions where repetition has no effect are particularly interesting in determining why repetition affects retention. A related topic of interest in the literature deals with the temporal distribution of repetitions. Generally, repetitions are more effective if they are spaced apart than if they are massed together (the spacing effect).

Anderson and Schooler (1991) have noted that both repetition and spacing effects are rational; that is, if one were designing an ideal memory system, one might construct it so that it would exhibit both of these phenomena. They pointed out that human memory evolved to manage a huge body of information containing millions of facts and experiences. Expecting perfect retrieval of all these facts is unlikely in the face of our limited physical abilities; it may also be unwelcome because we may quickly find ourselves overwhelmed by the massive amount of information we have stored. A rational memory system would be one where the retrievability of a memory is strongly related to the probability of that particular memory being needed. Repetition would surely be one clue indicating that a particular fact was important. If we had encountered or used a fact numerous times in the past, it would be more likely that we will need it again in the future than if we had only used that fact once. Similarly, when a particular fact or experience had been encountered or used at widely spaced intervals, it is probably more likely to be used again in the future than a fact used equally often but only in a massed cluster. Anderson and Schooler based their reasoning on theories of information retrieval, which underlie many of the computerized search systems found in libraries or on the Internet. Still, acknowledging that repetition effects and spacing effects are good phenomena for well-designed memory systems to show does not address the issue of the mechanisms that lead to these effects in human memory.

## 2.06.1 Continuity, Discontinuity, and Repetition

Coyne (2006) found that his golf practice (when not interrupted) led to a steady, albeit sometimes agonizingly slow, improvement in his performance. The seemingly continuous, but always slowing, effect of repeated practice is a ubiquitous finding in the field of learning and memory. The total amount learned increases as a function of repetition, but the rate of learning seems to change systematically across trials. The traditional learning curve depicted as a function of practice demonstrates negative acceleration, with the greatest learning occurring on the first trial. The amount learned on each subsequent trial seems to decline continuously. Eventually, the change in performance as a function of further practice is too small to be measurable. The phenomenon of *registration without learning* (Hintzman et al., 1992; Hintzman and Curran, 1995) is a demonstration of this, with participants showing no evidence of learning more information about the details of a stimulus, even while continuing to register its repeated presentations. Cleary et al. (2001) showed a similar pattern in learning about associations: When presented with word pairs that are repeated many times, participants may note the occurrence of individual items without showing improved associative memory. Because people seem to pay much less attention to later occurrences of repeated stimuli, first impressions become particularly important. Participants may not demonstrate evidence of having noticed small changes that are made to a stimulus after its first presentation (DiGirolamo and Hintzman, 1997). Miller et al. (2004) provided additional evidence regarding which features of a stimulus are most likely to be overlooked; specifically, accidental properties that are not inherent aspects of a stimulus are commonly ignored in later repetitions.

Authors such as Guthrie (1935) and Estes (1955) have long noted that this seemingly continuous improvement in performance does not necessarily mean that the learning process itself must be gradual or continuous. Many learning situations can be broken down into smaller components, and one cannot rule out the possibility that these components may be learned suddenly, possibly as a result of insight. If these components are learned at different times, the seemingly gradual nature of learning may instead reflect the accumulation of mastered components, each of which had been learned in a sudden all-or-none fashion. Distinguishing between a truly gradual learning process and the accumulation of numerous small insights is difficult, and it became common to assume that learning may be either gradual or sudden, depending on the situation and the nature of the participant. Harlow (1949) argued that learning to novel situations may be slow and continuous, but that sudden flashes of insight may occur when learning takes place in a familiar situation.

Rock (1957) was the first to move beyond the general concern that learning curves obscure sudden transitions in performance to an empirical methodology. He developed what became known as the drop-out procedure. He used a paired-associate methodology, in which participants had to learn a list of letter–number pairs. Study trials alternated with test trials, on which letters were presented and participants had to recall the corresponding numbers. After each test, Rock removed pairs that had not been answered correctly on that trial and replaced them with new pairs. Performance in this condition was compared to learning in a control condition, where participants were given the same unchanging list on multiple trials. The major finding was that there was no difference between the drop-out condition and the control condition; both groups mastered the list at the same rate. The fact that replacing old (but not yet mastered) pairs with new pairs did not impair performance led Rock to conclude that pairs were either completely learned or completely unlearned. Rock reasoned that if participants had been acquiring partial information about unrecalled pairs, performance should be impaired if such pairs were replaced by new ones. Because no impairment was found, he concluded that participants had not learned anything about a pair until the trial on which it could be recalled. That is, he argued for all-or-none learning: Rock believed that the fact that performance on a paired-associate list gradually improves across repeated study–test cycles obscures the fact that each pair is either entirely learned or unlearned, with the number of pairs moving from the unlearned to the learned state increasing across trials.

Rock (1957) acknowledged the fact that there was a potential flaw in his procedure. Some pairs are harder than other pairs. Presumably, the pairs that are not remembered on a particular trial would tend to be the most difficult pairs for that participant. In the drop-out condition, these particularly difficult pairs are being replaced on each trial by new pairs. Because the new pairs are randomly chosen to be added to the list, taken together they would be average in difficulty. Therefore, the drop-out group will end up with an easier list than the control group, which is stuck with the list that had been presented on the first trial. If this methodological flaw is serious, Rock would be mistaken in concluding that this methodology supports an all-or-none interpretation of learning. In later research, Steinfeld and Rock (1968) went to great lengths to argue that this artifact did not invalidate the drop-out procedure, but it is impossible to determine exactly how serious the problem is. Similar methodologies (e.g., that of Estes, 1960) run into analogous difficulties. In a review of this literature that was written just as research on this topic was winding down, Crowder (1976) noted this line of experimentation proved to be inconclusive but was valuable in shaking "the almost axiomatic belief of Ebbinghaus that repetition strengthens a unitary memory trace" (p. 273).

## 2.06.2 Basis of Repetition Effects

### 2.06.2.1 Theoretical Approaches

The philosopher Ward (1893) anticipated many of the later developments in theories of repetition effects. He distinguished between functional and atomistic accounts of repetition effects. Functional accounts would assume that repetition affects memory by altering a single location or representation. Every stimulus or experience has a particular trace in memory that is altered when it is encountered again. These alterations have the effect of making information about that stimulus easier to locate. Perhaps the most straightforward way of devising a functional account is to assume that memory traces differ along a single dimension, such as trace strength, so that this sort of approach is sometimes called strength theory. This approach is based on the assumption that repetition influences strength and that stronger traces are easier to remember than weaker traces. Ebbinghaus (1885/1964) seems to have implicitly adopted such a strength position, though his focus was on the strength of associations. Underwood (1969a) developed a somewhat more complex theory in which repetition-based strength was just one attribute that could vary among memory traces. On the other hand, atomistic theories maintain that two occurrences of an item lead to independent and distinct memory traces. Each of these traces would contain information about when it had been formed. Atomistic theories are more likely to be referred to now as multiple-trace theories. The German scientist Richard Semon, whose life and work in the early twentieth century has been described by Schacter (1982), was the first prominent multiple-trace theorist, although the model of memory proposed by the scientist Robert Hooke in 1682 can be interpreted in multiple-trace terms (Hintzman, 2003).

A fundamental difference between functional (strength) and atomistic (multiple-trace) accounts is in whether information about individual encounters with a repeated stimulus is maintained in memory. Functional accounts assume that repetition leads to the strengthening or alteration of a single location so that details about particular occurrences are lost. On the other hand, atomistic approaches claim that every occurrence leads to the formation of a separate memory trace, thereby maintaining the specificity of individual encounters. One class of experimental test of these approaches has focused on this fundamental difference by asking participants to make judgments about details of individual presentations of repeated events (see Hintzman, 2000, for a review of this approach). A pure strength theory would assume that participants would only be able to make a judgment about a stimulus by drawing an inference based on its strength; for example, a stronger stimulus can be assumed to have occurred more recently or more frequently. In contrast, multiple-trace accounts typically assume that each occurrence of a stimulus leads to the formation of a trace that records the context in which it was formed; therefore, participants would have access to detailed information about individual presentations of a repeated stimulus.

### 2.06.2.2 Judgments of Recency

To see how one might use memory judgments to discriminate between strength and multiple-trace approaches, a simplified account of a recency-judgment task (first developed for this purpose by

Morton, 1968) may be helpful. A participant may be given a list of digits and have to remember which of two test items had been presented later on the list. Imagine that a sequence like 7 5 2 9 1 6 5 8 4 3 is presented, and a participant is asked whether 4 or 5 had been presented later on the list. Note that 4 is the correct answer, but that the alternative 5 had been presented twice. According to strength theory, participants may tend to make the wrong choice because they may mistakenly attribute the heightened strength of the digit 5 to a recent presentation, as opposed to multiple presentations. In contrast, a multiple-trace account would claim that participants perform this task by retrieving occurrences of each digit and attempting to determine recency by examining details of each trace. Flexser and Bower (1974) carried out a systematic investigation of this task and concluded that multiple-trace approaches offered a better explanation of recency judgments. Hacker (1980) reached a similar conclusion by measuring response times in recency judgment.

### 2.06.2.3 Judgments of Frequency

There are several different ways in which one could test memory for frequency. One method would be a test of background frequency, which refers to the number of times that an event has occurred in one's lifetime. For example, Attneave (1953) studied the ability to make background-frequency judgments of letters of the English alphabet. These background-frequency judgments correlated .88 with the true frequency of occurrence in the English language, demonstrating that people are indeed sensitive to how often letters occur. Howes (1954) showed that people are sensitive to the background frequency of occurrence of words.

For the purpose of distinguishing between strength and multiple-trace accounts of repetition effects, tests of situational-frequency judgment are more useful. The prototypical way of studying situational-frequency memory is to present a list of words, which may be repeated varying numbers of times. At the time of test, list words are shown, and people have to indicate how often each was presented on the list. This sort of information is considered *situational* because participants do not have to remember how often items occurred throughout their whole lives but rather how often they occurred in a particular situation (i.e., on the laboratory list). People under typical testing circumstances are often very accurate, even when not expecting a test (Greene, 1984), leading some investigators to conclude that this sort of frequency information is encoded automatically (Hasher and Zacks, 1979, 1984). Although this claim of automatic encoding of frequency information is unlikely in the face of evidence that strategic factors may have a major impact on this task (Greene, 1984, 1986), all theoretical accounts of repetition effects must address why some information about frequency of occurrence is seemingly stored without intention. Strength and multiple-trace theories offer different explanations for how participants are able to estimate situational frequency. A strength theory would assume that participants access the memory trace corresponding to a test item and then assess the strength of that trace. The judgment of frequency is then based on the strength of that trace. For example, a very strong trace would be evidence that the corresponding item had occurred frequently on the list. On the other hand, a multiple-trace theory would assume that participants try to retrieve as many traces as possible of the test item. Those items that had occurred in the context of the list would then be counted, and a judgment of frequency would be based on that count (possibly after some adjustment to fit the expected ranges).

Results from the frequency-judgment literature tend to favor multiple-trace approaches. Although strength theory would have no problem in accounting for judgments of background frequency, it is not clear how this approach could explain people's ability to offer situational-frequency estimates that are independent of an item's overall background frequency. For example, strength theory would predict that background frequency should always contaminate situational frequency so that people should give higher situational judgments to items that occur more often in everyday life. In reality, situational judgments are largely independent of background frequency, and the slight effect obtained goes in the wrong direction: When situational frequency is held constant, participants give higher situational-frequency estimates to words of low background frequency than to words of high background frequency (Rao, 1983). Accuracy of frequency judgments is better for low-frequency words than for high-frequency words (Greene and Thapar, 1994).

Hintzman and Block (1971) carried out the classic demonstration of participants' ability to come up with specific situational frequencies. In this study, people were shown two lists of words, separated by a 5-minute interval. Each word occurred zero, two, or five times on each of the lists. These list frequencies were factorially crossed, so that the frequency of occurrence on one list would be completely uninformative as to the frequency of occurrence on the other list. After seeing the lists, participants were asked to estimate situational frequency of occurrence of each test word for each of the lists. The most important finding is that participants were very accurate on this task, so that their estimates of list frequency were chiefly determined by the true frequencies on the list being judged. Frequency of occurrence on the other list had only a small influence. The finding that people are able to make separate situational-frequency estimates for the same item in two lists is awkward for strength theory to explain: If these estimates were based solely on a unidimensional construct like strength, participants would not be able to make up these separate and largely independent estimates. On the other hand, multiple-trace theory would have no difficulty with this pattern, because these estimates would be based on a count of individual traces, each carrying information about the context in which it was created.

Greene (1990a, Experiment 5) carried out an even more extreme comparison of strength and multiple-trace approaches. Participants were given a list of words without being told what sort of test to expect. After the list had been presented, participants were shown a word accompanied by two other words. Participants had to choose which of the two accompanying words had been presented more frequently immediately before the single word. (For example, participants may have seen the word GOAT on the list three times. It may have occurred immediately after the word DIME two times and immediately after WALL once. DIME and WALL occurred elsewhere on the list, so that their total frequencies were equal. On the test, participants could be presented with GOAT, accompanied by DIME and WALL, and asked to pick the word that had preceded GOAT more often on the list. To be correct, they would have to pick DIME.) Participants had to answer this type of question for 36 words. Although this was a difficult test, all participants were able to perform above chance. Clearly, repetitions do more than merely strengthen a trace. Rather, every time a stimulus is presented, it leaves some sort of trace that records the context in which it had occurred.

### 2.06.2.4 Limitations on Multiple-Trace Accounts

Data from frequency-memory experiments provide strong evidence against the notion that repetition merely strengthens memories. It seems necessary to assume that repetition of stimuli leads to the storage of information that includes precise information about the time or context in which each presentation had occurred. However, this does not necessarily mean that repetition only leads to the formation of multiple traces. After all, it is possible that repetition has multiple effects. For example, it could lead both to multiple traces and to a strengthening of some representation in memory. There is some evidence that multiple-trace theories are not adequate for a complete account of the effects of repetition on memory.

#### *2.06.2.4.1 Effects of repetition on nonrepeated items*

A simple and pure multiple-trace account would claim that repeated presentations of an item should have the same effect on memory as presenting multiple once-presented items. For example, presenting 10 words three times each should lead to a functional list length of 30 items.

Let us consider a single once-presented item that may be presented in one of three conditions. In one condition, it is presented along with 10 once-presented words. In a second condition, it is presented along with 10 words, each presented three times, so that there would be a total of 31 presentations on the list. In a third condition, the item is presented along with 30 words presented once, so that there would again be a total of 31 presentations. We then administer a recognition test. We are interested only in recognition of the once-presented item. Recognition will certainly be influenced by the length of the list, but the critical issue would be if length should be defined in terms of total presentations (so that the second and third conditions are equivalent and should be more difficult than the first) or in terms of number of novel words presented (so that the first two conditions are equivalent, with the third being more difficult than the others). If one believes that repetitions act like presentations of new items by creating independent traces, then the second and third conditions should be equivalent. In reality, recognition is not influenced by total number of presentations but by the number of novel presentations so that the first and second conditions are both approximately equal and easier than the third (Ratcliff et al., 1990). The empirical picture is somewhat less clear-cut in free recall, but even here the effect of repeated presentations does not come close to matching the effect of added novel items (Tulving and Hastie, 1972; Ratcliff et al., 1990). Additional evidence that repetitions do not affect other items in the same way as a comparable number of distinct items was reported by Tussing and Greene (2001). This type of finding suggests that a simple application of the multiple-trace approach to repetition effects is inadequate.

#### 2.06.2.4.2 Superadditive effects of repetition on memory

Waugh (1963) observed that one can use simple laws of probability to derive expectations for memory of repeated items based on performance on once-presented items. Let us assume that two presentations of a repeated item lead to two completely independent memory traces. Recall or recognition of that item would be successful if the participant was able to retrieve one or both of these traces. If we define P as the probability of remembering a once-presented word, then the probability of remembering at least one occurrence of a repeated word should be $(2P - P^2)$ if the occurrences act like purely independent traces. This value can be considered an independence baseline, an indication of how high memory for repeated items should be if retention of separate occurrences was completely independent. Although not all studies find that recall of repeated stimuli significantly surpasses the independence baseline (e.g., Glanzer, 1969), there are numerous examples in the literature in which this has occurred (e.g., Johnston and Uhl, 1976; Goldman and Pellegrino, 1977; Overton and Adolphson, 1979). For reasons that are still unclear, the nature of the memory test seems critical, with performance on repeated items being more likely to exceed the independence baseline on recall tests than on recognition tests (Begg and Green, 1988).

At first glance, any reports of memory for repeated items exceeding the independence baseline might appear to be inconsistent with multiple-trace theories of repetition effects. After all, if multiple presentations of an item lead to the creation of separate traces, shouldn't retrieval of these traces operate just like retrieval of once-presented items? However, this argument is too simplistic. It overlooks the possibility that the memorability of an item might be affected by the fact that there were other occurrences of that item. For example, when a word is presented for a second time on a list, this repetition may remind the participant of the earlier occurrence, leading to further rehearsal and increased retrievability of the first presentation. (There is independent evidence that repeated presentations may lead to such a reminding process; see Hintzman and Block, 1973; Tzeng and Cotton, 1980; Winograd and Soloway, 1985). Thus, one cannot reject the multiple-trace approach simply because recall of repeated words may exceed the independence baseline. Rather, the multiple-trace approach suggests that the probability of recall should be predictable based on the probability of retrieval of the separate occurrences. To test the multiple-trace approach, some way must be found to allow for the experimenter to determine whether the participant is able to recall the first, second, or both occurrences of a repeated item.

Watkins and Kerkar (1985) devised such a study. The general procedure in their experiments was to ask participants to learn a list of once- and twice-presented words. Every presentation was tagged by an arbitrarily selected distinguishing attribute. Participants would be required to recall the words. Then they would be asked to remember the attributes. The goal was to determine whether memory for the items could be predicted on the basis of memory for the detailed attributes associated with particular presentations. Their first experiment can serve as an example of their approach. This experiment required recall of lists, each of which was composed of five words presented once and five words presented twice. The attribute manipulated here was the color of the presentations, with 10 different colors being used in printing the words. After the list was presented, participants were asked to recall the words. They recalled 0.18 of the once-presented words and 0.46 of the repeated words. (Note that recall of the repeated words greatly exceeded the independence baseline.) Then, Watkins and Kerkar attempted to determine whether recall of repeated items could be attributed to retrieval of particular occurrences. To determine how well particular occurrences could be retrieved, Watkins and Kerkar asked participants to remember the color that each word had been presented in, including noting two colors for repeated words. Participants were much less accurate in recalling the colors of repeated words than those of once-presented words. Thus, although people are able to recall repeated words better than would be expected based on recall of once-presented words, they actually remember the details of each occurrence of repeated words less well than they did for once-presented words. Watkins and Kerkar argued that there is a collective recollection of occurrences, which they called generic memory, that can benefit memory for repeated items separately from retrieval of the particular instances. Watkins and LeCompte (1991) presented further evidence that memory for repeated information can exceed recall of specific occurrences.

Hintzman (2004) had another demonstration that multiple-trace accounts cannot offer a complete account of repetition effects. He took what is commonly seen as the strongest evidence for these accounts, namely, participants' ability to estimate the frequency of occurrence of repeated items. He showed that these judgments of frequency were, in fact, more strongly related to presentation frequency than is performance on a recognition-memory test. Essentially, he dissociated memory for items from memory for how often they occur, although multiple-trace accounts attribute both to a common process (namely, the retrieval of separate occurrences). This finding is inconsistent with a pure strength-theory of repetition effects as well, because such a theory would also attribute the effects of repetition on recognition and frequency judgment to a single process, namely, the strengthening of a single trace for each stimulus. Fisher and Nelson (2006) carried out a conceptual replication of this finding by showing that the size of the repetition effect is numerically greater on frequency judgments than on recognition memory. These results suggest that any one-process account of repetition effects will be insufficient.

Overall, the literature suggests that repetition leads to the creation of separate memory traces, each of which contains information about the context in which it occurred. However, findings such as those of Watkins and Kerkar (1985) and Hintzman (2004) indicate that repetition has additional effects on memory beyond the creation of traces. These additional effects are at present still poorly understood. It is possible that a combination of strength and multiple-trace approaches will be necessary; formal models, such as that of Hintzman (1988), where repetitions create multiple traces that may be combined in various ways at the time of test, may eventually shed light on this. At present, however, we know that simple approaches are inadequate without yet being able to offer a successful complex explanation of repetition effects.

## 2.06.3 Spacing Effects in Memory

Ebbinghaus (1885/1964) noted that "with any considerable number of repetitions a suitable distribution of them over a space of time is decidedly more advantageous than the massing of them at a single time" (p. 89). This advantage of spaced practice over massed practice became one of the laws of memory formulated by Jost (1897). Spacing of repetitions became a widely used manipulation in studies of learning and memory (Bruce and Bahrick, 1992). Reviews of early research on this topic were carried out by Ruch (1928) and McGeoch and Irion (1952). However, given the wide variety of procedures used, many conflicting results were found, and researchers such as Underwood (1961) despaired of being able to demonstrate consistent and unambiguous benefits of repetition spacing. Melton (1967) rectified this by popularizing a straightforward way of demonstrating the beneficial effects of spacing. With this method, a list of words is presented one at a time to participants. Some of the words are presented two or more times, and the number of intervening items between occurrences of repeated items is carefully controlled. Some repeated words (massed words) are presented twice in a row, whereas other repeated words (spaced words) have one or more intervening words between occurrences. When participants are given a test on their memory for the words, a clear benefit for spaced repetitions over massed repetitions can be demonstrated. Recent reviews have established the advantage for spaced repetitions beyond serious question (Janiszewski et al., 2003; Cepeda et al., 2006). Although this conclusion had to be based on controlled laboratory experimentation, people evidently reach a similar conclusion based on their everyday experiences, as they may choose to devote spaced rehearsals to challenging material (Benjamin and Bird, 2006).

Several distinctions among commonly used terms may be useful. The advantage in memory for a repeated item over a once-presented item is a repetition effect. The advantage in memory for spaced items (repeated items that had their occurrences separated by intervening stimuli) over massed items (repeated items presented consecutively) is a spacing effect (sometimes called a distributed-practice effect). When one looks only at spaced items, any advantage in memory as the number of intervening stimuli is increased beyond one would be called a lag effect. Whether increases in spacing beyond one or two intervening items hold much benefit in remembering is less clear, although evidence increasingly suggests that this is the case (Kahana and Howard, 2005; Cepeda et al., 2006).

Spacing effects have received a large amount of attention from both theorists and experimenters. One reason why they are seen as particularly important is their wide generality. They may be found in a large number of subject populations, including nonhuman animals (e.g., Davis, 1970; Sunsay et al., 2004), human infants (Cornell, 1980), children (Toppino, 1991, 1993), and the elderly (Balota et al., 1989; Benjamin and Craik, 2001). Also, spacing effects have been found in educational settings for typical course materials, suggesting that the distribution of practice may be a useful way to improve retention without requiring additional time (Dempster, 1988). Bahrick (2005) has argued for the importance of viewing spacing effects from an educational perspective, and it is certainly true that spacing can influence long-term retention of material typically learned in school (e.g., Reder and Anderson, 1982; Rea and Modigliani, 1985; Bahrick and Phelps, 1987; Dempster, 1987; Rawson and Kintsch, 2005; Balch, 2006; Kerfoot et al., 2007).

A wide variety of theoretical explanations have been offered for spacing effects over the years. Although spacing effects may be found in many domains and using many tests, theorists have focused on the literature on human memory for word lists. At least with respect to this memory literature, two classes of explanation have been particularly influential, one emphasizing the importance of encoding and the other emphasizing the importance of retrieval.

### 2.06.3.1 Deficient-Processing Accounts

Some theorists (e.g., Hintzman, 1976; Zechmeister and Shaughnessy, 1980; Cuddy and Jacoby, 1982) have claimed that repetition spacing influences the processing of the second occurrence of repeated items. Typically, the claim is that massing repetitions leads to deficient processing of the second occurrence, relative to spaced repetitions. Hintzman et al. (1973) showed that repetition spacing seemed to influence memory for the details of the second occurrence, but not of the first occurrence, for repeated items.

This deficient processing of the second occurrence of repeated items may in part be due to involuntary processes akin to habituation; that is, we may not be able to keep ourselves from paying less attention to a stimulus that we had just encountered than one whose previous occurrences were more distant in time. However, it may well be that voluntary, strategic processes play a major role here. Zechmeister and Shaughnessy (1980) argued that, as participants are encoding a list of items, they are constantly deciding how to distribute their rehearsals between the current stimulus and the previous ones. The amount of rehearsal that a participant devotes to an item may be influenced by whether he or she feels that it is already well learned. There would be no point in devoting further rehearsal to an item that has already been mastered. Zechmeister and Shaughnessy found that participants overestimate the degree to which they will remember massed stimuli. They argued that this can lead to participants choosing to devote fewer rehearsals to such stimuli than to spaced items. Bahrick and Hall (2005) proposed a variant of this approach specifically aimed at retention over very long intervals.

There are many sources of evidence that converge on the claim that participants do not adequately encode the second presentation of massed items. When participants are asked to rehearse words aloud, they give fewer overt rehearsals to the second presentations of massed items than to the second presentations of spaced items (Rundus, 1971; Ciccone and Brelsford, 1974). When participants are allowed to pace themselves through a list presented on slides, they devote less exposure time to massed items than to spaced items (Shaughnessy et al., 1972; Zimmerman, 1975). Dilation of the pupil in the eye (a measure that is related to cognitive effort) is greater when participants are seeing spaced repetitions than when they are seeing massed repetitions (Magliero, 1983).

One straightforward test of this voluntary encoding account is to see whether spacing effects are eliminated when participants are not expecting a test on their memory for the material. That is, if participants are not deliberately rehearsing any items for a later test, then they would have no reason to treat spaced and massed items differently. The evidence here is strikingly mixed. Spacing effects are sometimes eliminated when lists are learned incidentally, but the details of the study and testing procedure are critical (e.g., Jensen and Freund, 1981; Greene, 1989, 1990b; Challis, 1993; Greene and Stillwell, 1995; Russo et al., 1998).

A second test for voluntary encoding-deficit accounts would involve an examination of the importance of experimental design. Repetition spacing could either be manipulated within lists (where participants are given a list containing both massed and spaced repetitions) or between lists (where participants receive a pure list, consisting either only of massed repetitions or spaced repetitions). The vast majority of studies in this area has used the within-list design. The magnitude of spacing effects in this design may be exaggerated because participants may rehearse spaced items during the presentation of massed items. If spacing effects result from an encoding deficit for massed items, you may see a reduction (and possibly a complete elimination) of spacing effects on between-list designs. Unfortunately, the literature on this point is very inconsistent, yielding all sorts of conflicting findings, and it is possible that the details of the design, study instructions, and memory test may be critical (Underwood, 1969b, 1970; Waugh, 1970; Greene, 1990b; Hall, 1992; Toppino and Schneider, 1999; Delaney and Knowles, 2005; Kahana and Howard, 2005).

Attempts to reduce spacing effects entirely to a voluntary deficient-encoding process, while inspiring some supportive results, have failed to present a consistent empirical picture. This has convinced some theorists that at least one other process is needed to explain spacing effects completely (Greene, 1989, 1990b; Braun and Rubin, 1998; Russo et al., 1998). In addition, it has been difficult to see how deficient-processing accounts developed to explain how participants remember intentionally learned lists of words can be easily expanded to cover the range of situations, materials, and subjects that can demonstrate advantages for spaced repetitions.

### 2.06.3.2 Encoding-Variability Accounts

Encoding-variability accounts of spacing effects make the assumption that the distribution of repetitions affects the likelihood that at least one of the occurrences will be successfully retrieved. Typically, it would be assumed that greater spacings would increase the probability that each presentation of a repeated stimulus would be encoded in a very different way, thereby making it more likely that a participant would be able to retrieve at least one of the occurrences.

One analogy that I have found useful in explaining this approach would be to liken this to the probability of being able to find a particularly important piece of paper. If you want to be sure that you will always be able to find the paper when you need it, you may try to have multiple copies of it. However, it would make no sense to place all of those copies in the same place. Rather, you should scatter the copies around at many different places. Although this would make it more difficult to locate all of the copies, it is assumed that you only need to locate one copy. Similarly, if every repetition of an item leads to a separate memory trace and if one only needs to retrieve one of the traces to remember the item, it would clearly be better if the separate traces are somehow distributed throughout memory.

This notion that repetition spacing influences encoding variability, which facilitates the probability of remembering at least one occurrence of an item, has been expressed in several forms. Landauer (1975) adopted this concept literally. He proposed a model in which memory traces are stored at random locations in a memory system. Traces for the occurrences of spaced items would tend to be stored farther apart than traces for the locations of massed items. If one assumes that only part of the memory space is searched during retrieval, then there would be an advantage for the spaced items.

An alternative way of envisioning encoding variability is with respect to the information with which items may become associated. For example, Glenberg (1979) suggested that interitem associations are critical on many memory tasks, particularly free recall. When two occurrences of a repeated item are presented in massed fashion, the two traces tend to become associated with the same items. In contrast, when the two occurrences are spaced apart, the resultant traces are associated with different items. Glenberg argued that the probability of retrieving at least one occurrence of a repeated item increases with the number of different associations that had been formed. Raaijmakers (2003) showed how this approach can be incorporated into a broader mathematical model of memory.

Gartman and Johnson (1972) pointed out that words can be interpreted in slightly different ways. This is clearest in the case of homographs like IRON or TOAST, where the same pronunciation and spelling pattern would be associated with seemingly unrelated meanings. Even when a word is perceived as having only one meaning, there may be slightly different connotations that could come to mind; depending on the context, the word PIANO could be encoded primarily as a musical instrument or as a heavy object. Gartman and Johnson suggested that repetition spacing influences the probability that each occurrence of a repeated word would receive a somewhat different interpretation and that this variability in meaning would increase the probability that at least one occurrence could be retrieved. Indeed, Gartman and Johnson reported that recall of homographic words does not show a spacing effect, presumably because different meanings may be invoked even at short spacings.

The notion that some variant of encoding variability underlies the spacing effect has been popular among theorists even in the absence of direct evidence that encoding variability benefits memory at all. Some interpretations of this approach would claim that encoding variability should influence memory for once-presented items; that is, the probability of retrieving at least one of two unrelated, once-presented words should increase as a function of the spacing between them. However, this prediction has been falsified, as spacing seems to have no effect on recall of once-presented words (Ross and Landauer, 1978). Also, direct attempts at controlling the presentation context of repeated items have found that encoding variability typically leads to a decrease in memory performance (Bellezza and Young, 1989; Greene and Stillwell, 1995; Verkoeijen et al., 2004).

Even in the absence of direct empirical support, the concept of encoding variability as at least one component in a theory of spacing effects continues to be popular. One reason is that some variants of this approach can offer a straightforward explanation for an otherwise puzzling finding, namely, the fact that memory for massed items may be superior to memory for spaced items if the test is administered very briefly after presentation. Glenberg and Lehman (1980) presented a particularly compelling empirical picture and proposed a proportionality rule that states that "when the retention interval is short relative to the spacing of the repetitions, performance is negatively correlated with repetition spacing; when the retention interval is long relative to the spacing intervals, performance is positively correlated with spacings of the repetitions" (p. 528). Glenberg and Lehman demonstrated this proportionality rule in free recall, with similar findings being obtained in other memory tasks (Peterson et al., 1963; Glenberg, 1976; see Cepeda et al., 2006, for a quantitative review of this pattern). This advantage for massed items after short retention intervals suggests that it is better to have two occurrences presented in contexts very similar to the testing context rather than to have only one. Although this finding of a massed-item advantage after brief retention intervals is only indirect support for encoding-variability approaches, it has been difficult to develop alternative explanations for this finding.

### 2.06.3.3 Multiprocess Accounts

Theorists have increasingly abandoned the attempt to reduce spacing effects to a single factor and have instead turned to multiprocess explanations, where spacing influences several aspects of memory (e.g., Glenberg, 1979; Greene, 1989, 1990b; Braun and Rubin, 1998; Russo et al., 1998). For example, Greene (1989, 1990b) has argued that deficient processing of the second occurrence of massed items largely explains spacing effects on tests where cues are provided to participants; such cued-memory tests would include recognition or frequency judgment. On the other hand, free recall is an uncued test because no retrieval cues are explicitly given to participants; some variants of the encoding-variability approach offer a better explanation of spacing effects on this test. This sort of explanation reflects the fact that one can find manipulations that have different effects on the spacing effect found in free recall or cued tests (e.g., Glenberg and Smith, 1981; Greene, 1989; Kahana and Greene, 1993). Still, the details of multiprocess approaches have yet to be worked out satisfactorily, as none has been able to offer a comprehensive account of the literature.

The popularity of multiprocess accounts largely reflects the fact that single-process explanations to date have necessarily left large portions of the literature unexplained. One limitation even for multiprocess accounts is that they have largely been applied only to results from memory experiments using adult human participants. In principle a factor like encoding variability can be applied to nonhuman animals (and indeed the concept owes much to the stimulus-sampling theory developed by Estes, 1955, to explain findings in the animal-learning literature). However, there has been little effort paid to seeing whether one can take theories of the spacing effect developed in the field of human memory and apply them in a fruitful way to other domains, such as animal conditioning or human skill acquisition. Until theorists in this area feel compelled to account for a wider range of empirical data, it will be impossible to claim that we have an adequate explanation of spacing effects.

## 2.06.4 When Repetition Does Not Improve Learning

Because repetition so clearly is an important factor in learning, it is understandable that we have focused on cases where there is a positive relationship. However, sometimes repetition is ineffective in promoting learning. The classic demonstration of this is the poor memory Americans have for the characteristics of the penny. Although Americans have seen this coin countless numbers of times, Nickerson and Adams (1979) showed that they can have quite poor recollection for its details. They may not be able to recall what words are on the penny or where the date is located. After all, people presumably use the color (brown) of the penny to distinguish it from other coins, so they do not need to attend to its other features. If people are given 15 s to study an unfamiliar coin (the mercury dime, which was in use from 1916 to 1945), they remember its details better than they remember those of the penny (Marmie and Healy, 2004). This illustrates the point that repetition in the absence of attention is strikingly ineffective in promoting learning.

The ineffectiveness of repetition in the absence of attention is also illustrated by the fate of items memorized through maintenance, or rote, rehearsal (e.g., Glenberg et al., 1977; Rundus, 1977). In these experiments, participants have to repeat items aloud over and over. When they are given an unexpected memory test on the rehearsed words, there is at best a very weak relationship between the number of overt rehearsals devoted to an item and later memory (Greene, 1987). Simply repeating an item over and over has little benefit for memory in the absence of attention or more elaborative processing of the material.

Repetition may impair learning if memory is tested for only one occurrence. If an item has been presented in several contexts, it may become difficult to retrieve the occurrence that is being tested. An early demonstration of this (although initially interpreted in a somewhat different way) was the negative part-whole transfer effect reported by Tulving (1966). In this procedure, a control group and an experimental group first learn a list of 18 words and then learn a list of 36 words. In the control group, the two lists are unrelated. In the experimental group, the earlier list of 18 words was then included in the list of 36 words. If repetition inevitably leads to improved memory, then the experimental group should have an advantage over the control group. However, Tulving found an effect in the opposite direction, with the control group outperforming the experimental group. A critical issue here is that there is increased opportunity for confusion between the lists when they overlap. Because participants in the experimental group do not necessarily realize that the 18-word list is entirely contained in the 36-word list, they may have difficulty when they try to restrict their recall to the second list (Sternberg and Bower, 1974). In a similar vein, preexposing some items on a list may impair recognition memory for them, at least in part because participants have difficulty knowing whether the familiarity of the items is due to the preexposure or to presentation on the list (Greene, 1999). Repetition may impair memory when the critical task requires participants to disregard some occurrences of a repeated stimulus.

A striking case where repetition may lessen memory is in serial (ordered) recall of short lists. When participants have to recall short lists of digits or letters, memory is impaired if one item is repeated on the list. This phenomenon, known as the Ranschburg effect, was introduced into the modern psychological literature by Crowder and Melton (1965). Crowder (1968) carried out a systematic manipulation of all possible locations of repeated items. He found that, when the two occurrences of a repeated item occupy immediately adjacent serial positions, recall of the series is enhanced. However, when the two occurrences are spaced apart, recall is impaired, with the greatest decrement occurring when there are two intervening items. The impairment is very localized, with only recall of the second occurrence being negatively affected. The Ranschburg effect is also rather delicate, leading Murdock (1974) to label it the "Ranschburg (non) Effect" (p. 297). Later research has shed light on the boundary conditions of this phenomenon, as changes in the nature of either the instructions given or the nature of the test can eliminate the effect (Greene, 1991). This effect seems to occur because recall of the first occurrence of the repeated item may inhibit output of the second occurrence (Greene, 2001).

## 2.06.5 Conclusion

Much of the literature on repetition and spacing effects has been carried out in the empirically minded spirit of functionalist psychology, so it is perhaps appropriate that strong conclusions can be drawn about empirical patterns but only tentative ones about theoretical implications. First, it is clear that the development of learning as a function of repetition is established beyond question in the research literature. Second, performance improves as a smooth, negatively accelerated function of frequency of study, though this does not necessarily imply that all aspects of learning take place gradually and continuously. Third, as a result of repeated practice, we form memories that contain the details of each occurrence and that we can access individually. Fourth, the effects of repetition cannot be reduced merely to retention of these separate episodes, as we seem to form generic memories that capture what these individual presentations have in common. Fifth, the effects of repeated study are enhanced if the study episodes are spaced apart in time. Sixth, these spacing effects are most likely due to a combination of factors, such as deficient processing of massed repetitions and superior retrieval for spaced repetitions. Seventh, repetitions may not always enhance memory, particularly when little attention is paid to a stimulus or when accurate remembering requires access to one particular occurrence of an event.

Although the theoretical implications of repetition and spacing effects remain to be worked out, their practical importance is beyond question (Dempster, 1988; Bahrick, 2005). Admittedly, much of the literature on these topics has followed standard laboratory methods employing word lists and college-student participants, thereby exhibiting the strenuous task reductionism typical of memory research (Crowder, 1985). Still, a meta-analysis carried out by Cepeda et al. (2006) suggested that repetition and spacing effects may influence learning for a wide variety of materials and over long retention intervals. As a wider range of procedures and perspectives are directed at these issues, we may hope to achieve greater theoretical progress in understanding these central manipulations for learning and memory.

## References


Anderson JR and Schooler LJ (1991) Reflections of the environment in memory. *Psychol. Sci.* 2: 396–408.

Attneave F (1953) Psychological probability as a function of experienced frequency. *J. Exp. Psychol.* 46: 81–86.

Bahrick HP (2005) The long-term neglect of long-term memory: Reasons and remedies. In: Healy AF (ed.) *Experimental Cognitive Psychology and Its Applications: Decade of Behavior*, pp. 89–100. Washington, DC: American Psychological Association.

Bahrick HP and Hall LK (2005) The importance of retrieval failures to long-term retention: A metacognitive explanation of the spacing effect. *J. Mem. Lang.* 52: 566–577.

Bahrick HP and Phelps E (1987) Retention of Spanish vocabulary over 8 years. *J. Exp. Psychol. Learn. Mem. Cogn.* 13: 344–349.

Balch WR (2006) Encouraging distributed study: A classroom experiment on the spacing effect. *Teach. Psychol.* 33: 249–252.

Balota DA, Duchek JM, and Paullin R (1989) Age-related changes in the impact of spacing, lag, and retention interval. *Psychol. Aging* 4: 3–9.

Begg I and Green C (1988) Repetition and trace interaction: Superadditivity. *Mem. Cognit.* 16: 232–242.

Bellezza FS and Young DR (1989) Chunking of repeated events in memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 990–997.

Benjamin AS and Bird RD (2006) Metacognitive control of the spacing of study repetitions. *J. Mem. Lang.* 55: 126–137.

Benjamin AS and Craik FIM (2001) Parallel effects of aging and time pressure on memory for source: Evidence from the spacing effect. *Mem. Cognit.* 29: 691–697.

Braun K and Rubin DC (1998) The spacing effect depends on an encoding deficit, retrieval, and time in working memory: Evidence from once-presented words. *Memory* 6: 37–65.

Bruce D and Bahrick HP (1992) Perceptions of past research. *Am Psychol.* 47: 319–328.

Cepeda NJ, Pashler H, Vul E, Wixted JT, and Rohrer D (2006) Distributed practice in verbal recall tasks: A review and quantitative synthesis. *Psychol. Bull.* 132: 354–380.

Challis BH (1993) Spacing effects on cued memory tests depend on level of processing. *J. Exp. Psychol. Learn. Mem. Cogn.* 19: 389–396.

Ciccone DS and Brelsford JW (1974) Interpresentation lag and rehearsal mode in recognition memory. *J. Exp. Psychol.* 103: 900–906.

Cleary AM, Curran T, and Greene RL (2001) Memory for detail in item versus associative recognition. *Mem. Cognit.* 29: 413–423.

Cornell EH (1980) Distributed study facilitates infants' delayed recognition accuracy. *Mem. Cognit.* 8: 539–542.

Coyne T (2006) *Paper Tiger*. New York: Gotham.

Crowder RG (1968) Intraserial repetition effects in immediate memory. *J. Verb. Learn. Verb. Behav.* 7: 446–451.

Crowder RG (1976) *Principles of Learning and Memory*. Hillsdale, NJ: Erlbaum.

Crowder RG (1985) Basic theoretical concepts in human learning and cognition. In: Nilsson L-G and Archer T (eds.) *Perspectives on Learning and Memory*, pp. 19–37. Hillsdale, NJ: Erlbaum.

Crowder RG and Melton AW (1965) The Ranschburg phenomenon: Failures of immediate recall correlated with repetition of elements within a stimulus. *Psychon. Sci.* 2: 295–296.

Cuddy LJ and Jacoby LJ (1982) When forgetting helps memory: An analysis of repetition effects. *J. Verb. Learn. Verb. Behav.* 21: 451–467.

Davis M (1970) Effects of interstimulus interval length and variability on startle-response habituation in the rat. *J. Comp. Physiol. Psychol.* 78: 260–267.

Delaney PF and Knowles ME (2005) Encoding strategy changes and spacing effects in the free recall of unmixed lists. *J. Mem. Lang.* 52: 120–130.

Dempster FN (1987) Effects of variable encoding and spaced presentations on vocabulary learning. *J. Educ. Psychol.* 79: 162–170.

Dempster FN (1988) The spacing effect: A case study in the failure to apply the results of psychological research. *Am Psychol.* 43: 627–634.

DiGirolamo GJ and Hintzman DL (1997) First impressions are lasting impressions: A primacy effect in memory for repetitions. *Psychon. Bull. Rev.* 4: 121–124.

Ebbinghaus H (1885/1964) *Memory: A Contribution to Experimental Psychology*, Ruger HA and Bussenius CE (trans.). New York: Dover.

Ericsson KA (2005) Recent advances in expertise research: A commentary on the contributions to the special issue. *Appl. Cogn. Psychol.* 19: 233–241.

Estes WK (1955) Statistical theory of spontaneous recovery and regression. *Psychol. Rev.* 62: 145–154.

Estes WK (1960) Learning theory and the new ''mental chemistry.'' *Psychol. Rev.* 67: 207–223.

Fisher SL and Nelson DL (2006) Recursive reminding: Effects of repetition, printed frequency, connectivity, and set size on recognition and judgments of frequency. *Mem. Cognit.* 34: 295–306.

Flexser AJ and Bower GH (1974) How frequency affects recency judgments: A model for recency discrimination. *J. Exp. Psychol.* 103: 706–716.

Gartman LF and Johnson NF (1972) Massed versus distributed repetition of homographs: A test of the differential-encoding hypothesis. *J. Verb. Learn. Verb. Behav.* 11: 801–808.

Glanzer M (1969) Distance between related words in free recall: Traces of the STS. *J. Verb. Learn. Verb. Behav.* 8: 105–111.

Glenberg AM (1976) Monotonic and nonmonotonic lag effects in paired-associate and recognition memory paradigms. *J. Verb. Learn. Verb. Behav.* 15: 1–15.

Glenberg AM (1979) Components-levels theory of the effects of spacing of repetitions on recall and recognition. *Mem. Cognit.* 7: 95–112.

Glenberg AM and Lehman TS (1980) Spacing repetitions over 1 week. *Mem. Cognit.* 8: 528–538.

Glenberg AM and Smith SM (1981) Spacing repetitions and solving problems are not the same. *J. Verb. Learn. Verb. Behav.* 20: 110–119.

Glenberg AM, Smith SM, and Green C (1977) Type 1 rehearsal: Maintenance and more. *J. Verb. Learn. Verb. Behav.* 16: 339–359.

Goldman SR and Pellegrino JW (1977) Processing domain, encoding elaboration, and memory trace strength. *J. Verb. Learn. Verb. Behav.* 16: 29–44.

Greene RL (1984) Incidental learning of event frequency. *Mem. Cognit.* 12: 90–95.

Greene RL (1986) Effects of intentionality and strategy on memory for frequency. *J. Exp. Psychol. Learn. Mem. Cogn.* 12: 489–495.

Greene RL (1987) Effects of maintenance rehearsal on human memory. *Psychol. Bull.* 102: 403–413.

Greene RL (1989) Spacing effects in memory: Evidence for a two-process account. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 371–377.

Greene RL (1990a) Memory for pair frequency. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 110–116.

Greene RL (1990b) Spacing effects on implicit memory tests. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 1004–1011.

Greene RL (1991) The Ranschburg effect: The role of guessing strategies. *Mem. Cognit.* 19: 313–317.

Greene RL (1999) Role of familiarity in recognition. *Psychon. Bull. Rev.* 6: 309–312.

Greene RL (2001) Repetition effects in immediate memory in the absence of repetition. In: Roediger HL III, Nairne JS, Neath I, and Surprenant AM (eds.) *The Nature of Remembering: Essays in Honor of Robert G. Crowder*, pp. 267–281. Washington, DC: American Psychological Association.

Greene RL and Stillwell AM (1995) Effects of encoding variability and spacing on frequency discrimination. *J. Mem. Lang.* 34: 468–476.

Greene RL and Thapar A (1994) Mirror effect in frequency discrimination. *J. Exp. Psychol. Learn. Mem. Cogn.* 22: 687–695.

Guthrie ER (1935) *The Psychology of Learning*. New York: Harper.

Hacker MJ (1980) Speed and accuracy of recency judgments for events in short-term memory. *J. Exp. Psychol. Hum. Learn. Mem.* 6: 651–675.

Hall JW (1992) Unmixing effects of spacing on free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 608–614.

Harlow HF (1949) The formation of learning sets. *Psychol. Rev.* 56: 51–65.

Hasher L and Zacks RT (1979) Automatic and effortful processes in memory. *J. Exp. Psychol. Gen.* 108: 356–388.

Hasher L and Zacks RT (1984) Automatic processing of fundamental information: The case of frequency of occurrence. *Am Psychol.* 39: 1372–1388.

Hintzman DL (1976) Repetition and memory. In: Bower GH (ed.) *The Psychology of Learning and Motivation,* vol. 11, pp. 47–91. New York: Academic Press.

Hintzman DL (1988) Judgments of frequency and recognition memory in a multiple-trace model. *Psychol. Rev.* 95: 528–551.

Hintzman DL (2000) Memory judgments. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 165–177. New York: Oxford University Press.

Hintzman DL (2003) Robert Hooke's model of memory. *Psychon. Bull. Rev.* 10: 3–14.

Hintzman DL (2004) Judgment of frequency versus recognition confidence: Repetition and recursive reminding. *Mem. Cognit.* 32: 336–350.

Hintzman DL and Block RA (1971) Repetition and memory: Evidence for a multiple-trace hypothesis. *J. Exp. Psychol.* 88: 297–306.

Hintzman DL and Block RA (1973) Memory for the spacing of repetitions. *J. Exp. Psychol.* 99: 70–74.

Hintzman DL, Block RA, and Summers JJ (1973) Modality tags and memory for repetitions: Locus of the spacing effect. *J. Verb. Learn. Verb. Behav.* 12: 229–238.

Hintzman DL and Curran T (1995) When encoding fails: Instructions, feedback, and registration without learning. *Mem. Cognit.* 23: 213–226.

Hintzman DL, Curran T, and Oppy B (1992) Effects of similarity and repetition on memory: Registration without learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 657–664.

Howes D (1954) On the interpretation of word frequency as a variable affecting speed of recognition. *J. Exp. Psychol.* 48: 106–112.

Janiszewski C, Noel H, and Sawyer AG (2003) A meta-analysis of the spacing effect in verbal learning: Implications for research on advertising repetition and consumer memory. *J. Consum. Res.* 30: 138–149.

Jensen TD and Freund JS (1981) Persistence of the spacing effect in incidental free recall: The effect of external list comparisons. *Bull. Psychon. Soc.* 18: 183–186.

Johnston WA and Uhl CN (1976) The contribution of encoding effort and variability to the spacing effect on free recall. *J. Exp. Psychol. Hum. Learn. Mem.* 2: 153–160.

Jost A (1897) Die Assoziationsfestigkeit in Abhangigkeit von der Verteilung der Wiederholungen. *Z. Psychol.* 14: 436–472.

Kahana MJ and Greene RL (1993) Effects of spacing on memory for homogenous lists. *J. Exp. Psychol. Learn. Mem. Cogn.* 19: 159–162.

Kahana MJ and Howard MW (2005) Spacing and lag effects in free recall of pure lists. *Psychon. Bull. Rev.* 12: 159–164.

Kerfoot BP, DeWolf WC, Masser BA, Church PA, and Federman DD (2007) Spaced education improves the retention of clinical knowledge by medical students: A randomized controlled trial. *Med. Educ.* 41: 23–31.
Landauer TK (1975) Memory without organization: Properties of a model with random storage and undirected retrieval. *Cogn. Psychol.* 7: 495–531.
Magliero A (1983) Pupil dilations following pairs of identical and related to-be- remembered words. *Mem. Cognit.* 11: 609–615.
Marmie WR and Healy AF (2004) Memory for common objects: Brief intentional study is sufficient to overcome poor recall of US coin features. *Appl. Cogn. Psychol.* 18: 445–453.
McGeoch JA and Irion AL (1952) *The Psychology of Human Learning*, 2nd edn. New York: David McKay.
Melton AW (1967) Repetition and retrieval from memory. *Science* 158: 532.
Miller JK, Westerman DL, and Lloyd ME (2004) Are first impressions lasting impressions: An exploration of the generality of the primacy effect in memory for repetitions. *Mem. Cogn.* 32: 1305–1315.
Morton J (1968) Repeated items and decay in memory. *Psychon. Sci.* 10: 219–220.
Murdock BB Jr. (1974) *Human Memory: Theory and Data*. Potomac, MD: Erlbaum.
Nickerson RS and Adams MJ (1979) Long-term memory for a common object. *Cogn. Psychol.* 11: 287–307.
Overton RC and Adolphson CJ (1979) Multiple trace retrieval: A trace-to-trace retrieval process? *J. Exp. Psychol. Hum. Learn. Mem.* 5: 485–495.
Peterson LR, Wampler R, Kirkpatrick M, and Saltzman D (1963) Effect of spacing presentations on retention of a paired associate over long intervals. *J. Exp. Psychol.* 66: 206–209.
Raaijmakers JGW (2003) Spacing and repetition effects in human memory: Application of the SAM model. *Cogn. Sci.* 27: 431–452.
Rao KV (1983) Word frequency effect in situational frequency estimation. *J. Exp. Psychol. Learn. Mem. Cogn.* 9: 73–81.
Ratcliff R, Clark SE, and Shiffrin RM (1990) The list strength effect: 1. Data and discussion. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 163–178.
Rawson KA and Kintsch W (2005) Rereading effects depend on time of test. *J. Educ. Psychol.* 97: 70–80.
Rea CP and Modigliani V (1985) The effect of expanded versus massed practice on the retention of multiplication facts and spelling lists. *Hum. Learn* 4: 11–18.
Reder LM and Anderson JR (1982) Effects of spacing and embellishment on memory for the main points of a text. *Mem. Cognit.* 10: 97–102.
Rock I (1957) The role of repetition in associative learning. *Am. J. Psychol.* 70: 186–193.
Ross BH and Landauer TK (1978) Memory for at least one of two items: Test and failure of several theories of the spacing effect. *J. Verb. Learn. Verb. Behav.* 17: 669–680.
Ruch TC (1928) Factors influencing the relative economy of massed and distributed practice in learning. *Psychol. Rev.* 35: 19–45.
Rundus D (1971) Analysis of rehearsal processes in free recall. *J. Exp. Psychol.* 89: 63–77.
Rundus D (1977) Maintenance rehearsal and single-level processing. *J. Verb. Learn. Verb. Behav.* 16: 665–681.
Russo R, Parkin AJ, Taylor SR, and Wilks J (1998) Revising current two-process accounts of spacing effects in memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 24: 161–172.
Schacter DL (1982) *Stranger behind the Engram: Theories of Memory and the Psychology of Science*. Hillsdale, NJ: Erlbaum.
Shaughnessy JJ, Zimmerman J, and Underwood BJ (1972) Further evidence on the MP-DP effect in free recall learning. *J. Verb. Learn. Verb. Behav.* 11: 1–12.
Sunsay C, Stetson L, and Bouton ME (2004) Memory priming and trial spacing effects in Pavlovian learning. *Learn Behav.* 32: 220–229.
Steinfeld GJ and Rock I (1968) Control for item selection and familiarization in the formation of associations. *Am. J. Psychol.* 61: 42–46.
Sternberg RJ and Bower GH (1974) Transfer in part-whole and whole-part free recall: A comparative evaluation of theories. *J. Verb. Learn. Verb. Behav.* 13: 1–26.
Toppino TC (1991) The spacing effect in young children's free recall: Support for automatic-process explanations. *Mem. Cognit.* 19: 159–167.
Toppino TC (1993) The spacing effect in preschool children's free recall of pictures and words. *Bull. Psychon. Soc.* 31: 27–30.
Toppino TC and Schneider MA (1999) The mix-up regarding mixed and unmixed lists in spacing-effect research. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 1071–1076.
Tulving E (1966) Subjective organization and the effects of repetition in multi-trial free recall verbal learning. *J. Verb. Learn. Verb. Behav.* 5: 193–197.
Tulving E and Hastie R (1972) Inhibition effects of intralist repetition in free recall. *J. Exp. Psychol.* 92: 297–304.
Tussing AA and Greene RL (2001) Effects of familiarity level and repetition on recognition accuracy. *Am. J. Psychol.* 114: 31–41.
Tzeng OJL and Cotton B (1980) A study-phase retrieval model of temporal coding. *J. Exp. Psychol. Hum. Learn. Mem.* 6: 705–718.
Underwood BJ (1961) Ten years of massed practice on distributed practice. *Psychol. Rev.* 4: 229–247.
Underwood BJ (1969a) Attributes of memory. *Psychol. Rev.* 76: 559–573.
Underwood BJ (1969b) Some correlates of item repetition in free-recall learning. *J. Verb. Learn. Verb. Behav.* 8: 83–94.
Underwood BJ (1970) A breakdown of the total-time law in free-recall learning. *J. Verb. Learn. Verb. Behav.* 9: 573–580.
Verkoeijen PPJL, Rikers RMJP, and Schmidt HG (2004) Detrimental influence of contextual change on spacing effects in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 796–800.
Ward J (1893) Assimilation and association. *Mind* 2: 347–362.
Watkins MJ and Kerkar SP (1985) Recall of a twice-presented item without recall of either presentation: Generic memory for events. *J. Mem. Lang.* 24: 666–678.
Watkins MJ and LeCompte DC (1991) The inadequacy of recall as a basis for frequency knowledge. *J. Exp. Psychol. Learn. Mem. Cogn.* 17: 1161–1176.
Waugh NC (1963) Immediate memory as a function of repetition. *J. Verb. Learn. Verb. Behav.* 2: 107–112.
Waugh NC (1970) On the effective duration of a repeated word. *J. Verb. Learn. Verb. Behav.* 9: 587–595.
Winograd E and Soloway RM (1985) Reminding as a basis for temporal judgments. *J. Exp. Psychol. Learn. Mem. Cogn.* 11: 262–271.
Zechmeister EB and Shaughnessy JJ (1980) When you know that you know and when you think that you know but you don't. *Bull. Psychon. Soc.* 15: 41–44.
Zimmerman J (1975) Free recall after self-paced study: A test of the attention explanation of the spacing effect. *Am. J. Psychol.* 88: 277–291.

# 2.07 Coding Processes

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The questions of what people know and how they come to know it have been a topic of scholarly inquiry forever. At the level of individual knowledge, all that any of us know is represented in memory, and memory representations are just that, representations. Whatever the event may have been, the processes of perception and comprehension yielded a psychological experience, and it is that experience of the event that becomes the memory. In this sense, the memory is a code that represents the original event, but that code is all the knowledge we as individuals have of the event. With these premises, the importance of studying coding processes in memory is obvious. Answers to the questions of what the nature of the code is and how the code is formed are answers to the venerable questions concerning the nature of knowledge.

Widespread interest in issues of coding only appeared with the cognitive renaissance of the 1950s and 1960s. The concept of coding is rarely found in psychology texts prior to 1950, but by 1972, coding was said to be truly central to modern theories of memory (Bower, 1972). In this chapter, we examine the origins of the concept, which reveal the theoretical function served by coding and the reason for its centrality in modern theory. An overview of the methods used to study coding is provided, as well as some description of factors known to affect the coding process. Finally, two broad metaphors used to describe the memory code will be discussed, along with several specific ideas that represent each of the metaphors. The reader is warned of a major caveat about the discussion, namely, that the effects of variables associated with the memory test will not be described, nor will the theoretical coaction of coding and retrieval be part of the discussion. One must keep in mind that many of the effects described in this chapter are relative to the conditions of retrieval (*See* Chapter 2.16).

## 2.07.1 The Coding Process

The process of coding is an integral component of many natural and artificial phenomena. Generally, coding can be defined as the transformation of messages, signals, or states from one representational form to another. With this definition, the presence of coding in activities from espionage to metabolism becomes fairly obvious. One might reasonably wonder, however, why phenomena require the apparently superfluous process of changing forms of representation. That is, if the representations denote the same thing, why insert a process to change the form of the representation? Leaving aside esoteric forms of coding for purposes of deception and secrecy, the principal need for coding processes seems to be that the end user cannot work with the original form of the representation, and coding is necessary to transform the original representation into a useable form. Relevant examples here range from the various transformations of energy after it contacts sensory receptors and before it is "used" in the brain to the necessity of transforming a visual experience to linguistic code to inform someone of the experience.

### 2.07.1.1 Coding from the Computer Model

The meteoric rise in the use of coding as a psychological concept is largely because of the developments in information science and computer technology between 1948 and 1960. Shannon (1948) published a mathematical theory of an abstract communication system, an important component of which was the bits of information transmitted by the system. The theory was written in a general mathematical form such that information could take any conceivable form and be transmitted over any kind of channel. Some psychologists soon realized that the idea could be applied to human information transmission (e.g., Miller, 1956).

Dovetailing with the abstract notion of information transmission was the more concrete model of the computer as an information processor. By 1958, Newell et al. advocated that the mind be described as an information processing system modeled on the workings of computing machinery. Early in the history of computer science, the computer was conceptualized as a general-purpose symbol manipulator, and the insight that the mind could be construed as a symbol-manipulating system (e.g., Newell and Simon, 1972) provided the foundation for the use of a computer model in theoretical psychology. With this foundation in place, the analogy of specific computer functions such as buffers, stores, and retrieval to human information processing, especially memory, was recognized quickly. Among these specific functions was the process of coding.

For the computer, the fundamental process of coding is the transformation of the external input into the representation defined by the machine language. The analogy here to energy transformation in human sensation and perception is patent. For example, the effective energy contacting the visual receptors is electromagnetic energy, but the human brain cannot use this form of energy. The first coding in vision is the transformation from electromagnetic energy to chemical energy at the level of the rods and cones. In turn, the chemical energy is transformed to electrical energy for transmission through the optic nerve for use in the cortex. Less concrete but equally compelling analogies were drawn to cognitive descriptions of learning and memory. By the 1950s, verbal learning researchers knew that some nonsense syllables were more nonsensical than others. Syllables such as FDR, KLM, and CBS obviously were treated differently than JQN, XFV, PGW. The assumption that the nominal stimulus was the functional stimulus had given way to the admission of a proximal stimulus. With that concession, behavioral theory now needed a psychological process of coding to account for the transformation from nominal to proximal stimulus.

### 2.07.1.2 The Function of a Code in Psychological Theory

Codes serve as representations for some other object or event. Codes carry information, perhaps not in the precise form specified by Shannon's (1948) theory, but information in the sense of symbolically representing something else. For our purposes, codes are the psychological manifestation of prior experience. The experience can be in the immediate past, in which case we call the code a perception. As the past grows more distant, we refer to the code as a memory. All psychologists agree that behavior and thought are influenced by prior experience, and because the code is the representation of that experience, understanding codes and the processes that produce them looms large for cognitive theorists.

Codes serve another function for psychological theory that is rarely discussed. That is, codes dispel the mystery of action at a distance. To say that current thought and behavior are caused by prior experience begs the question of how something in the past can cause something to happen in the present. The stock answer to this question is that experience changes the individual, but the customized answer includes the form of this change. Different theories propose different kinds of codes, but in all cases, the stored code solves the problem posed by causal action at a temporal distance. The original event does not cause current thought and behavior but, rather, the coded version of that event, which is accessible at the time of the behavior or thought. Not everyone agrees that this use of the code to bridge the temporal gap is a good thing. Watkins (2002), for example, noted that memory has been reified by assuming that a residual of the original experience is maintained over time and that this characterization is unrealistic. Nonetheless, the search for the contents of the memory code has been quite active.

## 2.07.2 Breaking the Code

On the assumption that the memory code is the proximate cause of the past's influence on current thought and behavior, the question of what is encoded from a given experience has become a popular research agenda in learning and memory. As with many other concepts in science, the memory code cannot be observed directly. Consequently, a variety of methodologies have been developed to infer the nature of the representation of a particular experience. Each method comes with assumptions that allow the inference to follow, and thus it is important to explicitly acknowledge these assumptions. The following discussion is intended to update an earlier review by Tulving and Bower (1974).

### 2.07.2.1 Transfer Paradigms

The transfer paradigm is a venerable method for studying the effect of prior experience and inferring the nature of the code for that experience. The use of transfer rests on the assumption that the effect of prior experience is proportional to the similarity of the prior experience and the current task. Perhaps the first use of the transfer paradigm to measure encoding and storage was Ebbinghaus's (1964) savings method. The savings score is a ratio of the number of trials required for original criterion learning to the number of trials to reach the criterion on a subsequent attempt. This ratio is assumed to index the stored memory from initial learning in that memory, for the original experience obviates the need for new learning on the second experience. Thus, the goal of the savings method is to determine the amount of the original experience that is available at a later time.

In contrast, contemporary use of the transfer paradigm has focused on the qualitative characteristics of encoding, as attested to by the wide acceptance of the principle of transfer-appropriate processing (Morris et al., 1977). The reasoning is straightforward. If performance on the criterion test varies as a function of the similarity between the test and the prior experience, one infers that the code includes values from that dimension of similarity. As an example, consider an experiment by Jacoby (1983). Subjects studied words for memory either by reading the words or by generating the words from a fragment. Half of the subjects were given a test of recognition memory, and half were given a test of perceptual identification. Perceptual identification requires that words be read under conditions of severe visual degradation. Prior experience with the words facilitates perceptual identification accuracy, but as Jacoby (1983) showed, only if that experience is reading. Generation of the study words produced no positive transfer to perceptual identification, although generation yielded much higher recognition memory than reading. Jacoby's demonstration of differential transfer from reading and generating at study illustrates the use of transfer paradigm to infer the content of the code.

Negative transfer also can be used to infer the contents of the code. An early example is the release from proactive inhibition (PI) paradigm (Wickens et al., 1963; Wickens, 1970). The basic paradigm involved presentation of short lists of words for immediate recall. The lists were similar on some dimension; for example, all words could be exemplars of the same category. As can be seen in **Figure 1**, performance declined quickly over the first two to three study-test trials. The decline was identified as PI, the cause of which is competition among the codes. The basis of the competition is assumed to be similarity of the codes. Thus, the presence of proactive interference provides a basis for inferring that the code contains information corresponding to the dimension of similarity. The inference is validated by eliminating the similarity on the final list in the series and observing better performance than on the previous trial, the so-called release from PI, which is depicted in **Figure 1** in the shift condition.

Straightforward inferences about the code from the release from PI paradigm are complicated by data reported by Gardiner et al. (1972). They presented different instances from the same category over three study-test trials and observed PI buildup over the trials, as would be expected. On the fourth trial, subjects continued to see instances from the same category but under different conditions. The standard control condition received no special instructions and continued to show PI on the last trial. In another condition, subjects were informed prior to studying the list that the instances were all exemplars of a subcategory (e.g., water birds). Memory improved with these instructions, as would be expected if the dimension of encoding shifts from that of the first three trials. The critical condition is the third condition, in which the special instructions concerning the material were given after study and prior to recall. These subjects also evidenced release from PI, results consistent with an alternative view of the cause of PI buildup and release. That is, PI reflects the increasing ineffectiveness of a cue as more items are subsumed by that cue, all in accord with the principle of cue overload (Watkins and Watkins, 1975). Release from PI then is caused by the availability of an appropriate new cue. Note that in this interpretation, negative transfer in the release from PI paradigm is not informative about coding processes.

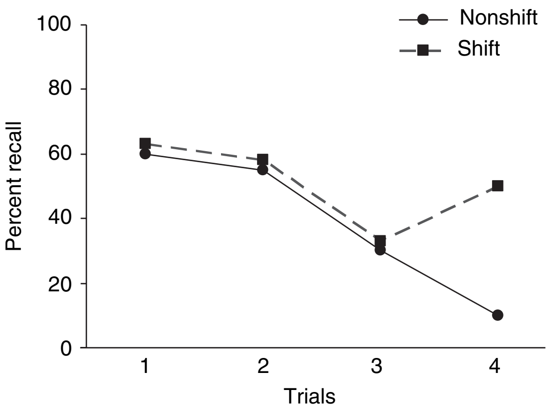


**Figure 1** Memory for material from the same category over the first three trials illustrates proactive interference. The shift condition sees material from a different category on the fourth trial, resulting in release from proactive interference. Adapted from Wickens DD, Born DG, and Allen CK (1963) Proactive inhibition and item similarity in short-term memory. *Journal of Verbal Learning and Verbal Behavior* 2: 440–445.

### 2.07.2.2 Retrieval Cuing

The relative effectiveness of retrieval cues frequently is used to make inferences about the nature of a code. The reasoning is the same as that underlying the use of the transfer paradigm, except that here the appeal is to the principle of encoding specificity (Thomson and Tulving, 1970; Tulving and Thomson, 1973). Encoding specificity states that as a necessary condition for successful memory, the cue must have been present at encoding. If a cue does lead to correct memory, one can assume, based on encoding specificity, that information shared by the cue and its target was encoded originally.

As an example, Nelson et al. (1974) used this logic to investigate semantic and phonetic coding of words. Word lists were studied for memory and then cued for recall by either rhymes or synonyms of the studied words. Half of the subjects who received rhyme cues had studied the words in the presence of the rhymes, and half had studied the words alone. Likewise, half of the subjects receiving synonym cues had studied the words in the presence of the synonyms, and half had studied the words alone. The results showed that recall to a rhyme cue was equally good for words studied in the presence of the rhyme and for words studied alone. Recall in the presence of the synonym cues was much better for the group that had seen the synonym cues at study than for the group that studied the items alone. From these results, Nelson et al. concluded that phonetic information about a word is encoded even when the word is not modified by a study context. Semantic information corresponding to the synonym is not encoded unless the study context biases that coding process. The results and interpretation make perfect sense, in that words have few alternative sound patterns, whereas the number of nuanced meanings of a word can be large.

The cuing methodology has been used extensively to study the interface between comprehension and memory. For example, Anderson et al. (1976) asked people to study sentences that contained a general noun (e.g., "The woman was outstanding in the theatre"). Later they were given a cued recall test and instructed to recall the last word of the studied sentences. The cue could be the general subject noun (e.g., 'woman') or a specific term that previous norming showed represented the comprehended instantiation of the general noun (e.g., 'actress'). Recall was better for the last word of the sentences when the cue was the particular instantiation rather than the general term that had appeared in the sentence. Using the logic of encoding specificity, Anderson et al. concluded that general terms are comprehended and encoded as particular instantiations rather than as abstract core meaning. This example nicely illustrates the relationship between questions about the memory code and the broad issue of the nature of knowledge. The conclusion from the Anderson et al. study suggests that the meaning of abstract nouns is represented by specific instances of those nouns rather than some abstract meaning that goes beyond the instances.

Using retrieval cues to infer the coded experience is limited to the logic of encoding specificity, namely, the presence of a cue at encoding is a necessary condition of cue effectiveness, not a sufficient condition. The implication of this limitation is that one cannot infer the nature of coding from the absence of a particular cue effect. For example, the declining performance over trials in a buildup of PI paradigm cannot be used to infer a corresponding decline in the encoding of the dimension of similarity across the trials, indeed, quite the opposite inference usually is made. In short, memory performance is affected by factors other than the presence of an appropriate cue. What can be done with some confidence is to infer that particular information was encoded when cue information facilitates memory. Nairne (2002) offers an interesting discussion of the limitations of cue effectiveness as a basis for inferences concerning the encoded trace.

### 2.07.2.3 Materials Effects

The existence of different kinds of codes also has been inferred from differential effects of material on memory. Perhaps the seminal modern instance of this approach involves comparing memory for a list of pictures versus memory for a list of words that are the names of the pictures. Other things being equal, the pictures will be better remembered than the words (e.g., Paivio, 1971). Paivio and others have interpreted these data as consistent with the idea that at least two classes of codes exist in memory, verbal and imaginal (Paivio, 1995). Pictures can be coded in both forms, whereas words are most likely to be coded in the verbal form, and the multiple forms of code for the pictures confer an advantage in memory performance. Alternatively, Nelson et al. (1976) suggested that the picture superiority effect is not a result of qualitative differences in the code but, rather, to a quantitative difference in the distinctiveness of the sensory code for pictures. Nelson et al. (1977), however, did argue for a difference in the necessity of semantic coding for words and pictures in that pictures require semantic coding prior to phonetic coding, whereas the semantic coding of words is not necessary for phonetic coding. Again, the nature of coding was inferred from the differences in performances for the classes of materials.

Variations in the memory code accompanying manipulations of materials have been used to explain other memory effects, including differences in memory as a function of clinical diagnoses. For example, clinically depressed patients tend to remember negatively valenced words better than positive words, whereas nondepressed people do not show this effect (e.g., Bradley and Mathews, 1983; McDowell, 1984). This effect is eliminated in tests that do not request intentional memory (e.g., Denny and Hunt, 1992; Watkins et al., 1992). Because prior research has shown that meaningfully elaborated codes are better remembered than less elaborated codes on intentional memory tests, these data have led to the conclusion that the encoded representation of negative experiences is more elaborate than the representation for positive experiences in depressed patients. The difference in memory for different types of materials as a function of clinical diagnosis is explained by inferring quantitative differences in the codes. Depressed patients have more elaborate codes representing negative events than do nondepressed people.

A potential problem associated with inferring the type of code from materials effects concerns the decision axis for postulating a class of codes. One would not postulate a qualitatively different class of codes for every dimension along which people can discriminate; otherwise, the kinds of codes would prove practically infinite. What was needed in 1974 (Tulving and Bower) is still not entirely obvious today, and that is a clear set of rules specifying when a differential effect of materials is evidence for different kinds of code. Moreover, care must be exercised to avoid the assumption that labeling material effects as different memory codes has explained anything. Discussing this issue, Tulving and Bower (1974) said, "it is of interest to note that it has not yet been made clear by anyone how the task of explaining memory phenomena is materially aided by the hypothesized existence of different memory stores" (p. 273).

### 2.07.2.4 Decision Time

Another method used to infer the nature of encoded material is the time taken to respond to queries about the prior experience. The assumption underlying this technique is that response time will be faster if the code contains the information requested by the query. The more inferences from the code required to answer the query, the longer the time will be. A good example of this approach comes from Posner's (1969) research. Subjects were shown two letters in succession, the first of which is the target letter, and the second is the probe. A decision is made as quickly as possible as to whether the probe matches the first target. Various matching rules can be used to instruct the subjects. Suppose the rule is that the two letters have the same name, and the target letter is a capitalized 'A.' The probe can either be a matching capitalized 'A' or one of two nonmatching probes, a lowercase 'a' or a different letter. When 'A' is followed by 'A,' the positive decision is made more quickly than when 'A' is followed by 'a.' The difference in decision latency decreases as the interval between the two letters increases. Assuming that the target letter is held in memory until the match is completed, Posner and his colleagues interpreted this pattern to indicate that the initial representation is visual, thus producing faster matches for visually identical patterns. As the encoding process continues, the visual code is supplemented by a phonetic code, leading to faster responding to the 'A-a' pair at longer interletter intervals.

Reaction time has been used extensively to infer imaginal coding in decision-making tasks (e.g., Brooks, 1967; Cooper and Shepard, 1973; Farah, 1985). As an example, Cave and Kosslyn (1989) showed stimuli consisting of two superimposed rectangles, one drawn in light lines and the other in dark lines. One of the rectangles was drawn vertically, and the other was superimposed diagonally over the first rectangle. The same two objects were used on each trial, although the relative length of the lines in the objects differed from trial to trial. The task was to decide whether the sides of the object drawn in light lines were equal to those of the object drawn in light lines on the previous trial. The principal manipulation was the subject's expectations of the size of the object to be judged and of which of the two rectangles would be drawn in light lines. The manipulation was performed by instructing the subjects that most of the time the same rectangle would be judged on the next trial and that the object would be of the same size as on the preceding trial. These instructions conformed to 75% of the trials. Thus, on 25% of the trials, the size, the object, or both were different from the preceding trial. The time to correctly decide about the targeted rectangle was affected by both expectations. Responses to unexpected objects as well as to unexpected sizes were slower. Considering just the expected object trials, response time increased linearly with the unexpected change in object size. These data indicate that the stimulus from the preceding trial affects performance on the current trial and that this effect systematically varies with the relative size of the stimuli. A reasonable interpretation is that the encoded representation from the previous trial affects performance on the current trial and that representation contains specific size information. That is, the representation is a visual image.

Although studies such as those of Posner and Cave and Kosslyn illustrate that reasonable inferences can be drawn about the nature of the code from decision latencies, one must be aware of the effect of speed–accuracy trade-offs when using latency data. Latencies in most tasks will vary as a function of the emphasis on speed or accuracy, and that trade-off can change the results of an experiment dramatically. Such changes could result in different conclusions about the nature of the code, when in fact the difference is essentially a strategy shift. Moreover, the use of decision latency tends to be limited to material on which accuracy of performance will be near perfect. Thus, the method is not appropriate for new learning or large amounts of to-be-remembered material.

### 2.07.2.5 False Memories

Memory is not always veridical to the past. People do remember things that did not occur, or at least did not occur as they are remembered. This fact has long been known and has been used as a tool to infer the qualitative nature of the original code. The assumption underlying this inference is that healthy memory is not capricious; rather, errors of commission in memory reflect the content of the coded representation of the probed experience. For example, early studies of false responding in recognition memory showed that synonyms and antonyms of studied words were seductive lures (Anisfeld and Knapp, 1968; Fillenbaum, 1969). The high false alarm rates for these distracters were taken to indicate that the coded representation of the study items was dominated by meaning. The same conclusion was drawn from studies that showed false recognition for sentences that expressed the same idea as studied sentences but were otherwise syntactically different from the studied sentences (e.g., Bransford and Franks, 1971). The coded representation of sentential content seemed to be the abstracted meaning of the sentence.

An important line of research that uses false memory to infer the nature of the code was initiated by studies of inferential processing in comprehension. The idea is that inferences are an integral aspect of normal comprehension and that the information implied in the inference would be part of the coded memory. For example, Johnson et al. (1973) reported a study in which subjects were asked to read several short descriptive stories consisting of two or three sentences. One story was: "John was fixing the birdhouse. He was pounding the nail when his father came out to watch him and help him do the work." The control condition saw the same story except 'pounding the nail' was replaced with 'looking for the nail.' In addition to the actual sentences presented in the story, the recognition test included inference sentences such as: "John was using the hammer to fix the birdhouse when his father came out to watch him and help him do the work." The test instructions were to recognize the sentences that were exactly the same as those presented at study. The group that received the study sentences that invited the tested inferences recognized approximately the same percentage of inference test items and studied sentences. Subjects given the control study sentences made few false alarms to the inference test items. These data are important indications that the coded representation of the prior experience includes the information from the inference, which apparently is indistinguishable from the presented material.

In a similar vein, Deese (1959) reported that people will intrude associatively related words in recall after studying a list of words that are all associated with unpresented words. For example, the study words might include 'sharp,' 'thread,' 'sew,' and 'pin,' but not the word 'needle.' On later recall tests, the probability of recall for the nonpresented associate often is equivalent to the recall of study items. Roediger and McDermott (1995) resuscitated this paradigm, and extensive research has been conducted using the paradigm to study false memories (see Roediger and McDermott, 2000a,b, for a review). A favored interpretation of the intrusions and false alarms that occur in this paradigm is that the critical item comes to mind during study and thus is encoded in the study episode. (*See* Chapter 2.14 for a thorough discussion of false memory.)

Past research has interpreted false memory to be the result of encoding either a general dimension or specific content such as an inference. This interpretation seems reasonable and, additionally, renders false memory less mysterious and capricious in that false memory very often is the product of the normal processes of comprehension of targeted material. One issue concerning inferences from false memory is whether the false memories result from encoding processes or occur at retrieval. For example, false memory of inferences from the Deese/Roediger/McDermott paradigm may be the result of the critical item coming to mind in the presence of targets in recall or recognition. That is, the inference occurs during the test rather than at study. Although this possibility cannot be ruled out entirely, two findings mitigate against an exclusive retrieval interpretation. One is that Roediger et al. (2001) report that false recall is negatively related to correct recall. If the false item were coming to mind as the result of recalling its associates, one would expect a positive relationship between these factors. The second finding is that warnings about false recall are more effective if issued prior to study rather than following study (McDermott and Roediger, 1998; Gallo et al., 2001; Neuschatz et al., 2003; but see McCabe and Smith, 2002, for contrary data).

### 2.07.2.6 Orienting Tasks

Orienting tasks, usually judgments that the subject makes concerning the to-be-remembered material, can have a powerful influence on recall and recognition (e.g., Hyde and Jenkins, 1969). With Craik and Lockhart's (1972) levels of processing came a wave of experiments manipulating orienting tasks, all of which assumed that these tasks exert their effect at least in part through specific encoding of a dimension of the material. The logic here is straightforward. If the memory trace is a by-product of perception and comprehension, and the focus of perception and comprehension can be controlled by the orienting instructions, then the qualitative content of the trace can be identified with the dimension specified by the orienting task. For example, Jacoby and Goolkasian (1973) gave subjects lists of word pairs, each of which was related either categorically or acoustically. The orienting task was to rate the degree of the relationship within the pairs. The subjects rating categorical relations recalled more of the items than the subjects who rated the acoustic relationship. The difference in memory is attributed to the nature of the trace (i.e., representations of categorical meaning lead to better memory than sound patterns).

Orienting tasks often are used in conjunction with other methods to infer the nature of the code. For example, Chan et al. (2005) combined the use of orienting tasks and the Deese false memory paradigm to examine the effect of associative versus phonological encoding on false memory. Study lists were either semantically or phonologically related words, and in both cases all the study words were related to a word that was not presented (e.g., 'bed,' 'rest,' 'awake,' or 'sweep,' 'steep,' and 'sleet' are all related to 'sleep,' which itself was not presented). The orienting instructions were to concentrate on the relationship among the words' meanings or among the sound patterns of the words. These instructions were orthogonal to the type of relationship among the words in the lists. The results, which are shown in **Figure 2**, showed an impressive crossover interaction between type of list and orienting task on false memory for the nonpresented items. Considerably more false memory occurred when the orienting task was congruent with the dimension of similarity in the study list. A reasonable interpretation of these data is that the orienting task controls the dimension of encoding and that the critical associate will only come to mind if the study items are coded on a dimension shared by the critical item. That is, if I see *sweep, steep, and sleet*, I will only think about *sleep* if I am attending to the sound of the words.

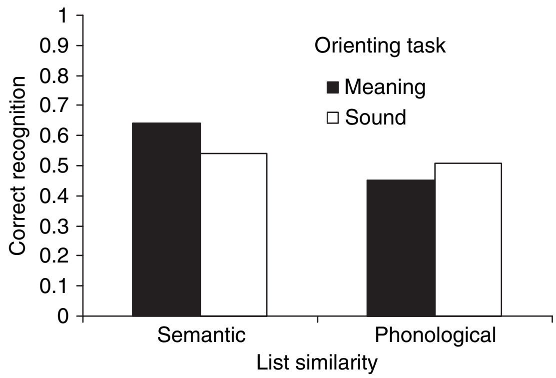


**Figure 2** False recognition of critical words as a function of the type of list similarity and orienting task. Adapted from Chan JC, McDermott KB, Watson JM, and Gallo DA. (2005) The importance of material-processing interactions in inducing false memory. *Mem. Cognit.* 33: 389–395.

Despite enormous amounts of research using the technique, we know that orienting tasks alone are not sufficient to identify the content of the code. Leaving aside the possibility that subjects may intentionally focus on dimensions other than that associated with the orienting task, incontrovertible evidence shows that orienting tasks do not control completely the dimension of encoding. For example, Nelson et al. (1979) found that the meaning of a word was encoded in a context that emphasized phonetic features. Hunt et al. (1979) report that visual features of words are encoded during semantic orienting tasks. The encoding of sensory attributes in the course of making a semantic judgment is quite reasonable given that the semantic processing requires sensory input, but this fact complicates the inference one can make about the code following an orienting task.

### 2.07.2.7 Neural Indices of the Code

A relatively new technique for identifying the code is the use of noninvasive, neural-dependent measures that record brain activity during encoding. The logic of identifying psychological functions from observations of neural dependent measures was formulated in the early 1800s by pioneers such as Gall and Spurzheim, but the development of powerful imaging techniques has made the idea more appealing than ever. A succinct statement of the neuroscientific approach to identifying the memory code begins with the assumption that experiencing an event results in activation of neural pathways that are dedicated to the processing of those types of events.

This activation leaves a trace in the form of altered neural functioning such as increased connectivity. This neural trace will be a critical participant in later memory of the event when activation occurs under appropriate conditions. Using this logic, the trace is identified as the site of the brain activity. To translate the neural code to a psychological code, one appeals to the assumed localization of the psychological functioning (e.g., visual/occipital, auditory/temporal, verbal/temporal-frontal, spatial/parietal, emotional/limbic).

An informative example of the logic underlying the neural identification codes is the study of imagery and memory. A dispute erupted in the 1970s over the nature of the code in memory for an imagined event. The dispute had two aspects. Is the code a modality-specific representation or some more abstract, post-perceptual code (e.g., Shepard, 1978)? And is the mental image a spatial representation or a propositional representation (e.g., Kosslyn, 1980)? Although these appear to be straightforward empirical issues, they proved resistant to adjudication by standard methods of experimental psychology (see, e.g., the following sequence of papers, Kosslyn et al., 1978; Pylyshyn, 1981; Intons-Peterson, 1983).

In the face of this stalemate, some argued that neural techniques are the panacea, "neural measures have the potential to be more decisive on these issues because they provide more direct evidence on the internal processing stages intervening between the stimulus and response in imagery experiments" (Farah, 1995, p. 964). In her reviews of research using various techniques to monitor regional brain activity during mental imagery, Farah (1995, 2006) showed that virtually every study implicates occipital activity in mental imagery, demonstrating that imagery and perception share cortical representations. Moreover, some of these shared cortical representations include spatially mapped areas of the occipital lobe. Thus, if one is willing to assume that the cortical representation is the psychological experience, the neural techniques have resolved successfully what appeared to be an intractable debate about the code underlying mental imagery.

Another interesting example of the use of brain measures to address a question of coding is described by Tulving (1989). The question was, Are there different kinds of codes for knowledge and memory? Tulving reported PET scans of brain activity when the subject was thinking of a recent Sunday afternoon picnic and when thinking of news accounts of French elections. In the best of the Ebbinghaus tradition, Tulving himself was the subject. The results of the scan showed activity in different brain regions when remembering the Sunday picnic than when reflecting on knowledge of the French elections, evidence interpreted to be consistent with the notion that memory and knowledge are represented by different kinds of codes.

Another important line of research using neural techniques was initiated by Wagner et al. (1998). The goal was to identify the locus of brain activity during encoding that is associated with remembered items but not forgotten items. fMRI scans were performed as the to-be-remembered words were presented, and then the scans were backsorted following a recognition memory test to determine what differentiated recognized items from nonrecognized items. Comparing high-confidence hits to misses, greater activity was seen in multiple prefrontal regions and left parahippocampal and fusiform gyri for the hits. Effectively, the conclusion is that relatively high activation in these areas established the code for successful memory. Paller and Wagner (2002, p. 93) have labeled this technique the "subsequent memory paradigm," which yields the contrast between neural activity for successfully remembered and forgotten items. Subsequent use of the paradigm has replicated the original Wagner et al. (1998) results and moved on to issues such as the correlates of coding underlying the subjective experiences of remembering versus knowing (see Paller and Wagner, 2002; Kahn et al., 2004, for reviews).

Research on coding processes that use neural-dependent measures is an exciting development that has produced new information about the brain correlates of learning and memory. However, as with all the other techniques described here, certain cautions are in order if one's goal is to specify as precisely as possible the memory code. Especially important is an issue raised by Henson (2005, 2006) and Poldrack (2006), which is analogous to deductive versus inductive inferences from behavioral data. In the case of behavioral studies of coding processes, a deductive inference would be one in which memory is predicted from a theoretical view of the nature of the code, whereas an inductive inference would be one in which the nature of the code is induced from the behavior. The latter, of course, is the much frowned upon *post hoc* explanation. In the case of the neural measures, the deductive inference is one in which brain activity is predicted from some theoretical idea. Tulving's (1989) study described earlier is an example of the deductive inference based on neural measures. The hypothesis was that two different kinds of memory codes exist, and the study measured brain activity in the situations that hypothetically activate one or the other of the codes. Notice that the precise regions of brain activity are not critical for the conclusion drawn from the data.

In contrast, the inductive inference, the postulation of a memory code from observation of brain activity, is based entirely on the region of the brain that is activated. Farah's (1995) conclusion that mental imagery is modality specific is based on the assumption that visual perception is mediated by the occipital cortex. Activation of that structure is used to infer visual experience. Not only is the specific brain region important when making these inductive inferences from brain to psychological function but the mapping of structure to function also must be one-to-one (Henson, 2005, 2006; Poldrack, 2006). If any reason existed to assume that the occipital cortex were involved in propositional coding as well as visual perception, one could not infer anything about a particular code from its activation. Thus, if the goal is to specify a particular encoding operation from neural data, one must be able to specify not only what brain area is associated with that operation but also that the brain area is only associated with that particular type of code.

#### 2.07.2.8 Summary of Methods

Memory scientists have been extraordinarily clever at developing techniques to study the nature of the representation in memory. The work is difficult because no direct observation of the memory code is possible, but rather, the code must be inferred from observations of behavior and/or brain activity. The use of indirect inferences to establish the nature of the representation is not at all unique to the question of coding, or even to psychology. It is the same hypotheticodeductive strategy that has led to the postulation of planets and subatomic particles. In contrast, the rules that govern an inference from observations to a specific hypothetical code must be made explicit in each case and examined for their validity.

The challenge confronting the attempt to precisely specify the code in any given circumstance was argued by Anderson (1978). Anderson's point was that inferences about the code are based on data, which in turn were collected under the auspices of theory-driven experiments. That is, a theory predicts some outcome given some setting condition. The problem arises when we realize that a theory postulating a particular code (e.g., a visual image) also assumes some set of processes. Any data explained by this theory also may be explained by an alternative theory that postulates an alternative form of representation (e.g., a propositional code) combined with alternative processes. Anderson concluded that for this reason, arguments about contents of the code cannot be adjudicated by behavioral research. Anderson's only suggested solution was the possibility that neural-dependent measures would become available, and as evidenced by Farah's opinion quoted earlier, some scientists believe that the solution has been achieved in the intervening years. That belief, however, rests on the assumption that the neural measure is a more direct observation of the code.

## 2.07.3 Factors Affecting the Coding Process

Acquisition and retention of information are determined in part by the circumstances surrounding the initial experience. It is these factors that are classified as the variables affecting encoding. Understanding the effects of these variables is complicated by the fact that criterion performance is affected not only by the coding process but also by the circumstances surrounding the test. Among the major advances in the study of learning and memory is the widespread appreciation for the relativity of the effect of both study conditions and test conditions, each of which constrains the other. Thus, the effect of encoding variables on later performance is relative to the nature of the test. Consequently, in contrast to earlier conceptualizations of learning and memory, we no longer make absolute statements about the general effect of acquisition variables. Nonetheless, the study of factors constituting the encoding environment continues to be a focal area of memory research. In this section, some of that research and its allied phenomena are described.

#### 2.07.3.1 Intent to Remember

Intuitively, intent to remember emerges as a dominant factor affecting later memory, but research on encoding processes has shown that intuition unequivocally to be wrong (e.g., Postman, 1964; Hyde and Jenkins, 1969; Craik and Lockhart, 1972; Challis et al., 1996). As we shall see, what does matter is the type of processing performed on the material, but trying to remember does not ensure that optimal processing will be engaged. **Figure 3** depicts the results reported by Hyde and Jenkins (1969). Subjects were asked to determine the words' pleasantness, check all of the 'e's in the word, or count the vowels in each word. For three groups of subjects, the orienting tasks were given as incidental memory instructions, and for another three groups the orienting tasks were accompanied by instructions to try to remember the words. As can be seen in **Figure 3**, adding intentional instructions improved performance in the nonsemantic orienting groups but had no effect on the performance following the pleasantness rating task. It is not the intent to remember but, rather, the nature of the processing that is important.

Indeed, an enduring contribution of levels of processing (Craik and Lockhart, 1972) is the acceptance of memory as a by-product of the processes of perception and comprehension of the original experience rather than as the intentional object of processing. After all, how many times during the course of the day does one try to remember, and yet healthy adults can remember most everything that happened yesterday. Furthermore, only occasionally do we know what, if anything, about current experience will be required from memory, rendering intent to remember any part of the experience a gamble against future demands. In light of these considerations, the lack of direct effects of intentional memory is understandable.

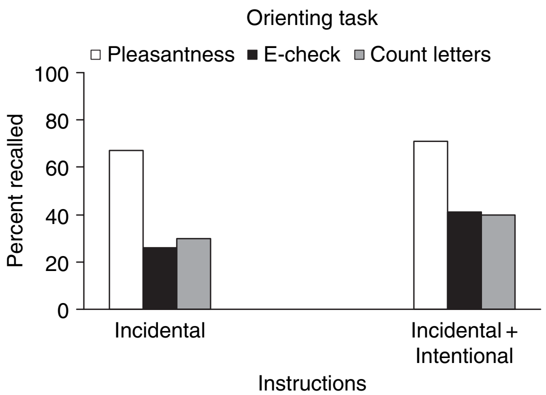


**Figure 3** Memory as a function of type of orienting task and intention to remember at study. Adapted from Hyde TS and Jenkins JJ (1969) Differential effects of incidental tasks on the organization of recall of a list of highly associated words. *J. Exp. Psychol.* 82: 472–481.

### 2.07.3.2 Attention

Coding processes to memory are influenced substantially by both quantitative and qualitative aspects of attention. Qualitative aspects of attentional processing are inferred from the effects of selective attention on memory, and those effects are encompassed by levels of processing. In addition to the effects of selective attention, evidence indicates powerful effects of the amount of attention devoted to encoding. Dividing attention between processing a to-be-remembered event and another activity at encoding comes at a cost to both.

Seminal projects by Baddelely et al. (1984) and Craik et al. (1996) both found that memory was affected negatively by dividing attention at the time of study and also that performance on the secondary task used to divide attention was negatively affected. This research clearly shows that coding processes require attentional capacity. More recent reports (e.g., Fernandes and Moscovitch, 2000; Naveh-Benjamin et al., 2005) have substantiated the earlier conclusion, rendering as apparent the fact that optimal memory for a prior experience requires allocation of conscious processing to that experience. This conclusion only applies to memory tests in which the individual intends to remember, an important example of the caution urged about conclusions concerning encoding without consideration of the retrieval context.

### 2.07.3.3 Types of Processing

Beginning with Hyde and Jenkins (1969), it became increasingly apparent that memory could be influenced powerfully by asking subjects to perform tasks that focused attention on various aspects or dimensions of the to-be-remembered material. Hyde and Jenkins concluded that the effect of these tasks can be attributed to the "nature of the stored trace" (1969, p. 480). As research intensified, the characteristic of the trace that determined performance took center stage. Hyde and Jenkins had contrasted tasks that required subjects to rate the pleasantness of words, to count the number of 'e's in the words, or to estimate the number of letters in the words. The pleasantness rating task invariably produced better recall, and in contrasting the three tasks, Hyde and Jenkins speculated that the difference lay in the fact that the pleasantness rating task required the words to be treated as meaningful units. This idea would be refined and elaborated by Craik and Lockhart (1972) in one of the most influential papers in the coding literature.

#### *2.07.3.3.1 Levels of processing*

Beginning with Estes's (1959) stimulus sampling theory, the notion that objects and events can be conceptualized as multidimensional has been routinely adopted in memory research. Encoding processes function to analyze experience along its various dimensions and select values on those dimensions to represent an experience in memory. The code can be described as the set of these values or features, or alternatively, at a more macro level, the code can be identified with a broad dimension (e.g., phonetic code). Research such as that of Hyde and Jenkins (1969) suggested that encoding semantic features yielded better memory for the event than encoding orthographic features, and Craik and Lockhart (1972) systematized findings such as these with their idea of levels of processing. The idea itself will be discussed later, but the empirical work surrounding the idea uncovered a powerful factor affecting the coding process.

The idea of levels of processing was simple, and the experimental paradigm that it fostered was easily implemented and produced huge effects, factors responsible for dozens of published papers demonstrating the basic effect in the wake of Craik and Lockhart's paper (Watkins, 2002). The effect originally reported by Hyde and Jenkins is that semantic encoding produces superior memory, but the research expanded the characterization to a broad dichotomy between semantic and nonsemantic encoding. The superiority of semantic encoding was demonstrated not only for memory for lists of words, but also for higher-order language constructions (e.g., Perfetti, 1979), and even faces (e.g., Bower and Karlin, 1974). **Figure 4** represents the results of Bower and Karlin's study, in which subjects studied faces by judging their honesty, likableness, or gender. Subsequent recognition memory for the faces was much more accurate following judgments of honesty and likableness. In the wake of the immense volume of literature provoked by levels of processing, one marvels that the basic effect of superior memory following semantic processing remains unexplained (Roediger and Gallo, 2002).

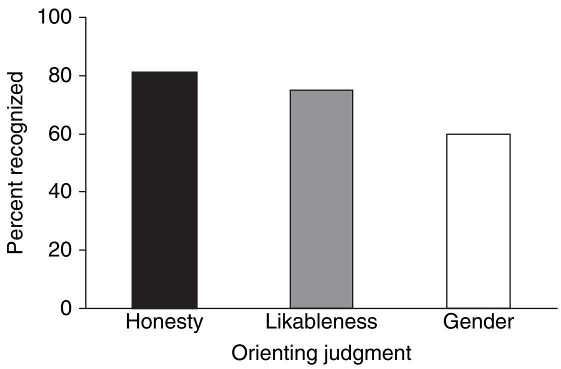


**Figure 4** Recognition of faces as a function of judging honesty, likeableness, or gender when studying the faces. Adapted from Bower GH and Karlin MB (1974) Depth of processing of pictures, faces, and recognition memory. *J. Exp. Psychol.* 103: 121–156.

#### *2.07.3.3.2 Self-generation*

Slamecka and Graf (1978) convincingly showed that memory for self-generated material is better than memory for externally provided material. This generation effect is operationally distinct from levels of processing in that the generation paradigm requires subjects to generate a word in the presence of highly constraining cues. For example, subjects may be told to generate antonyms of cue words that also fit the letter fragment (e.g., 'hot–c_ _d'). Other subjects either hear or see lists of the same word pairs and are asked to remember the second member of each pair. Other things being equal, the generated items are much better remembered than the externally provided items.

Similar to levels of processing, generation effects have no consensually agreed upon explanation, and little empirical work currently is devoted to this problem. Nonetheless, generation is a powerful encoding factor. Just how powerful is nicely illustrated in a study by Slamecka and Fevreiski (1983). They arranged a generation list that would yield tip-of-the-tongue states. Subjects were asked to generate words in response to dictionary definitions, and sometimes subjects could not generate the word but would report feeling that they knew that word. The control condition read the definitions followed by the word. **Figure 5** depicts the remarkable outcome, which was that the words that were not generated but were on the tip of the tongue were recalled better that the same word when it had been read.

The generation effect is limited to meaningful material; no generation advantage in memory occurs with meaningless material (Graf, 1980; McElroy and Slamecka, 1982), suggesting a possible connection between the psychological processes mediating generation and levels of processing effects. The generation effect also was eliminated in a study by Donaldson and Bass (1980), in which the subjects in the nongenerate condition were required to judge the quality of the relationship between the cue word and the target. The effect of this manipulation was to

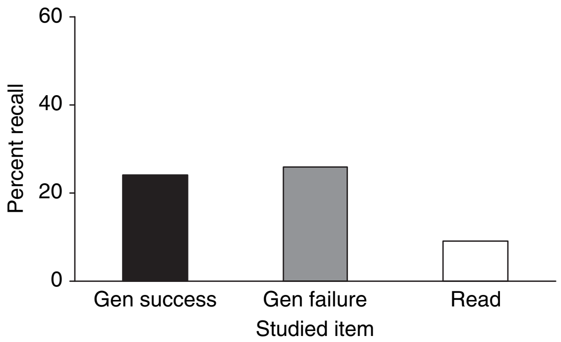


**Figure 5** Correct recall as a function of successfully generating, trying but failing to generate, or reading the word at study. Adapted from Slamecka NJ and Fevreiski J (1983) The generation effect when generation fails. *Journal of Verbal Learning and Verbal Behavior* 22: 153–163.

elevate performance in the nongenerate group to the level of the generate group, suggesting that the effect is a result of the attentional focus required by generation.

Begg and his colleagues have made a similar argument based on the premise that the generation effect was the result of impoverished processing of nongenerated items. Begg et al. (1991) demonstrated that generated and read items are equally well remembered if the quality of the processing of the items is equated. For example, if both the generation and read condition are asked to construct images of the words, no difference appears in memory as a function of generation. If both conditions are asked to pronounce the words, the generation condition now shows an advantage in memory. The interpretation of these data entails an important applied message about memory coding; namely, generation requires discriminative encoding processes that transfer to later memory demands, whereas perceptual processing of incoming information may or may not attract beneficial discriminative encoding.

#### 2.07.3.3.3 Organizational processing

Levels of processing and generation research largely have studied memory for unrelated words and have produced descriptions of item-specific coding processes. However, coding of relationships among items has long been known to be important to memory (e.g., Katona, 1940). The modern era of research on organizational coding was launched by Miller's (1956) proposal that discrete elements could be coded into higher-order chunks for storage in short-term memory. The function of such coding was to increase storage capacity by increasing the amount of information in the stored unit. Tulving (1962) later emphasized enhanced retrieval efficiency as the functionally significant impact of organization.

The most straightforward evidence for the importance of organizational processing is found in studies of memory for materials that contain known relationships. For example, word lists consisting of exemplars of known categories are better remembered than random lists, and categorized lists are better remembered when the category exemplars are presented contiguously than when they are presented in random order (Bousfield, 1953; Mathews, 1954). That an active coding process intervenes between list presentation and recall can be inferred from the fact that recall of randomly presented categorized lists tends to come out organized by category. Further evidence of active organization comes from Tulving's (1962) demonstration of subjective organization. Here multiple study-test trials occur for an unrelated list of words, which is presented in a different order on each study trial. Over the trials, a stable output ordering tends to develop – an ordering that is different from the various input orders and is usually idiosyncratic across subjects. The importance of organizational coding to memory has been argued from the almost perfect correlations Tulving found between his measure of organization and free recall.

The dependence of memory on organizational processing also is evident from the phenomena of whole-to-part and part-to-whole negative transfer. Tulving (1966) demonstrated that when subjects learn an initial list to criterion and then are given a second list to learn, half of which comprises the first list items, learning of the second list is impaired relative to a condition that learns an unrelated first list. Similar negative transfer was reported by Tulving and Osler (1967) when the second list consisted of half of the items from the first list. Tulving (1968) suggested that these data indicate the importance of organizational encoding to learning, in that the organization of the first list items interferes with learning (active organization) of the second list. This interpretation subsequently was supported by data showing that positive transfer could be arranged from list 1 to list 2 if list 1 organization is appropriate to list 2 learning (Bower and Lesgold, 1969; Ornstein, 1970).

#### 2.07.3.3.4 Distinctive processing

Laboratory studies promoting the importance of distinctiveness to retention have been reported for over 100 years (e.g., Calkins, 1894), research that parallels the intuition about the memorability of distinctive events. Despite, or perhaps because of, the intuitive appeal of distinctiveness as a factor at encoding, some confusion surrounds the meaning of the concept of distinctiveness (Hunt, 2006). The most common usage has distinctiveness as a property of events, as in the polka-dot Volkswagen in the funeral procession. In this view, distinctiveness is a property of events, and as such, distinctiveness cannot be explained by appeal to distinctiveness for obvious reasons of circularity. Rather, the standard approach has been to appeal to processes at encoding that entailed a subjective experience, usually of surprise or salience (Green, 1956), which in turn garnered attention in the form of additional processing of the distinctive event (Jenkins and Postman, 1948). In this view, distinctiveness has a quantitative effect on the encoding process.

Interestingly, the standard account of distinctiveness cannot explain the data from von Restorff's (1933) classic paper, which is peculiar because the standard account has been developed largely from data on the isolation effect. The isolation effect refers to enhanced memory for a target item that differs from the other items in the context, which themselves are similar on some dimension. The isolation effect refers to superior memory for the isolated item compared with memory for the same item, in the same serial position of a nonisolated control list. The items of the control list can be either all similar on some dimension or all different. The isolation list conforms to intuitions about what constitutes a distinctive event in that the target item violates the prevailing context. von Restorff was not the first person to use an isolation paradigm, but she was the first person to place the target item early in the list. Her reasoning was that at the early serial position, no context for the list has been established, and the isolate will not be perceived as salient. Nonetheless, the early isolate was better remembered than the corresponding control item. von Restorff's data pose a problem for the standard interpretation of distinctiveness as extraordinary processing attracted by the salience of isolate.

An alternative approach to distinctiveness began as an effort to integrate levels of processing and organization. Humphreys (1976) made the case that optimal encoding of an experience would include both the relationship among the elements comprising the experience as well as information about the elements themselves. Einstein and Hunt (1980) and Hunt and Einstein (1981) were able to demonstrate that the combined effects of organizational encoding and item-specific encoding led to better memory than either alone. Hunt and McDaniel (1993) suggested that the combination of relational and item-specific processing constitutes distinctive processing, using the argument that relational processing refers to processing of dimensions common to all items of an event, and item-specific processing refers to processing of properties of individual items not shared by other items in the event. The combination of relational and item-specific processing then precisely specifies a particular prior item, a description that captures the important discriminative function of distinctive processing. In this view, distinctive processing at encoding is defined as the processing of difference (item-specific properties) in the context of similarity (relational information). Nairne (2006) also has developed ideas about distinctiveness and memory that treat distinctiveness as a psychological phenomenon rather than as a property of events. Nairne's approach defines distinctiveness as the extent to which a particular cue complex specifies a particular event. As with the combination of item-specific and relational processing, Nairne's theory attributes the benefit of distinctive processing to the development of diagnostic information used in retrieval, rather than to quantitative differences in coding processes as specified by the standard treatment of distinctiveness. (For a more extensive discussion of distinctiveness, *See* Chapter 2.09.)

### 2.07.3.4 Prior Knowledge

Experience within a domain enhances memory for new events within the experienced domain. The more you know about something, the more likely it is that you will remember new information about something (Kimball and Holyoak, 2000). Moreover, this effect is presumed to be largely the result of encoding processes. One line of research leading to this conclusion is the study of experts' memory. Chase and Simon (1973) compared the memory of master chess players with that of novices for various arrangements of pieces on a chessboard. In some cases, the pieces occupied the positions of actual games in play, and in other cases the pieces were randomly arranged on the board. After briefly viewing the board, the subjects were asked to reproduce what they had seen. The experts remembered more than the novices when the boards were based on actual games, but when the pieces were randomly presented, memory was no longer affected by differences in prior knowledge. The superior memory of the experts was explained as the use of prior knowledge to organize the encoding of a new experience. The experts' advantage disappears outside the domain of expertise, such as with the random arrangement of chess pieces. The results described here for chess apply to other domains, such as bridge, music, medicine, and computer programming (see Ericsson and Lehman, 1996, for a review).

Without disputing the contribution of organizational encoding, evidence has been offered to show that prior knowledge also increases the likelihood of distinctive encoding. Van Overschelde et al. (2005) asked people to remember a list of names of college and professional football (American-style) teams. The list consisted of 10 teams' names. In one case, nine of the teams were professional, and one was a college team, whereas in the other case, all 10 teams were college teams. The lists thus comprised an isolation paradigm. Typically, the isolated item is better remembered than the corresponding item in the all-similar list, an effect attributed to distinctive processing of the target item in the isolation list. Van Overschelde et al. selected people for their experiment who were either knowledgeable about football or not. The result was that the experts recalled the critical item better when it appeared in the isolation list than in the control list, but no isolation effect occurred for the nonexperts. This result suggests that experts encode not only the similarity among items within their domain of expertise but also the differences among these items. That is, prior knowledge seems to influence not only organizational encoding but also distinctive processing.

## 2.07.4 Characterizations of the Code

A final science of memory will know the neural code for prior experience and have a set of mapping rules to relate that code to the psychological states of memory. Until we reach that final stage, psychological concepts of memory codes will guide our thinking about phenomena of learning and memory. The specific nature of stored information has been characterized in virtually countless ways (e.g., traces, engrams, nodes, images, processes, features, vectors of features, production rules, or logogens). A particular characterization of codes often is driven by the phenomenon under study. For example, research into the effects of learning and memory in problem solving and skill learning often uses a production rule as the code (e.g., Anderson, 1983). What is learned and stored in memory is characterized as an if–then statement in the form of condition–action sequences. This characterization is descriptive of skilled performance in the domain of problem solving in that successful problem solving entails producing a particular action in a particular circumstance. Proposals for particular codes also result from the processing requirements of a theory in which the code is embedded. For example, Neisser's (1967) pioneering theory of pattern recognition proposed that the first step of the recognition process was the analysis of the sensory pattern into units that are stored in long-term memory. These units essentially serve as the data on which processes operate, much as real numbers serve as the database for arithmetic operations. The units used by Neisser were features – a concept that continues to have broad appeal.

Among the myriad descriptions of the memory code, one can detect two general issues that distinguish classes of codes. One of these issues is whether the code should be characterized as structure or process. The structural metaphor perhaps is the more common and more intuitive conceptualization. Here the memory code is a residual, often called the trace, of the prior experience, which is stored in a memory system. The alternative metaphor is that of skill. Here the memory code is represented as a mental process. The skill metaphor is very different from the structural metaphor in that processes are not stored; just as skills are nowhere when you are performing them, memory is nowhere when you are not remembering. These different metaphors lead to interesting differences in memory research, including that on coding, and we examine briefly some of the principle representatives of the two metaphors.

The second general issue concerns the existence of abstract codes; that is, codes for prior experience that are not bound by a particular prior context. The existence of abstract codes has been championed by philosophers as the product of rational thought since at least the time of Plato, and no one seriously studying cognitive processes questioned the reality of abstract codes until quite recently. To some extent, the positions on the abstraction issue are correlated with the first general issue, with the structural metaphor being more compatible with the notion of abstract representations; however, the correlation is not perfect.

### 2.07.4.1 The Structural Metaphor

Structural analysis of the mind evolved from two important but very different models. The first is exemplified by Titchener's (1898) admirably clear statement of structuralism, in which of the goal of psychology was modeled on morphology in biology. According to Titchener, the job of the experimental psychologist was to perform "vivisection of the mind which shall yield structural results" (p. 450). The parts of the mind would be revealed by this analysis in much the same way that parts of the body are revealed by morphological analysis. It is precisely this kind of thinking that leads to research attempting to determine the constituents of the memory code that was described earlier.

The second model influencing modern structuralism is the computer. Application of the computer model to human cognition allowed a distinction between structural components and control processes that modeled the distinction between programming commands that are fixed and commands that are contingent on the content. Atkinson and Shiffrin's (1968) theory proposed that certain psychological processes are voluntary (control processes) and that certain structural components of information processing are fixed. The fixed components were memory systems, which are defined in part by the kind of code stored. Thus, coding processes are intimately bound to particular memory systems within a structural analysis. Different structural analyses yield different kinds of codes, as we see in the following discussion.

#### 2.07.4.1.1 Stage theory of information processing

Atkinson and Shiffrin's theory exemplifies the stage analysis of the mind that characterized the halcyon days of information processing. Learning was a matter of transporting information from sensory reception to storage in long-term memory. The trip occurred in three stages. Each stage was a memory storage system, and each system required a different code.

The first stage of processing was the sensory memory store, which theoretically held codes in the form of raw sensory information. Groundbreaking work by Sperling (1960) provided evidence for the existence of a very short-lived memory that contained no meaning, characteristics that fit perfectly with a sensory code. Sperling's work on the visual store was complemented by Darwin et al.'s (1972) report of data suggesting the existence of an auditory store that holds acoustic sensory codes.

The second stage of processing culminated in storage in short-term memory. An important part of the processing was the recoding of the sensory information to its corresponding phonetic form. Evidence for a phonetic code in short-term memory was derived from studies showing interference in memory for short lists of words as a function of phonetic similarity (e.g., Baddeley, 1966). The argument that the code for short-term memory is the sound pattern of the material fit neatly with the importance assigned to rehearsal. That is, rehearsal typically is assumed to be a verbal process, and verbal processes require speech codes.

The final stage of processing was the transfer of information from short-term to long-term memory. Rehearsal was assumed to be the important mechanism of transfer, by which the phonetic code was recoded into its corresponding semantic representation. Again, the evidence for a semantic code in long-term memory was derived from studies showing that semantic similarity interfered with performance on tests of long-term memory (e.g., Baddeley, 1966).

Thus, the stage theory assumed that information processing is characterized in part by coding processes that recoded the information from a previous stage to a form appropriate for storage in the higher stage. In the strongest statement of the theory, the form of the code was assumed to be a structural component, which means that the code has to be in the specified form if the information is stored in the particular system. That is, nothing but a phonetic trace can be stored in short-term memory. Consequently, it is not surprising that research showing that the code in short-term memory could be visual (e.g., Posner, 1969), or even semantic (e.g., Shulman, 1974), raised concern about the stage model. One reaction to the theoretically incongruent data was to revise the model of short-term memory in light of the new evidence on the nature of the code.

#### 2.07.4.1.2 Working memory

The concept of working memory emerged as a revised description of short-term memory (Baddeley and Hitch, 1974) in the wake of the stage model's failure. Working memory is different from the stage model in several dimensions, the most important of which for us is the question of coding. Rather than assume a single store containing a phonetic code, working memory's structure includes three separate storage structures to accommodate three different codes. The structure of working memory includes a phonological loop that stores a phonetic code, a visuo-spatial sketchpad that stores a visual code, and an episodic buffer that stores semantic codes (Baddeley, 2000).

Evidence for the independence of the storage systems and their structurally bound codes was inferred from studies of interference. For example, the existence of a phonetic code has been inferred from the interference produced by the phonetic similarity effect (Baddeley, 1966), but this effect can be eliminated under certain circumstances. If the word lists are presented visually and the subject is required to repeat the word 'the' as rapidly as possible during list presentation, phonetically similar lists are remembered just as well as control lists. If, however, presentation of the lists is auditory, the phonetic similarity effect does occur; that is, the phonetically similar list is more poorly remembered than the control list. These data and their interpretation are drawn from Baddeley et al. (1984), who argued that auditory input gains obligatory access to the phonological loop but that visual input requires recoding to a phonetic form. This recoding is performed by the articulatory control process, but that process also is responsible for the production of speech. Thus, rapidly repeating the word 'the' during visual presentation of the list prevents phonetic recoding and storage in the phonological loop. As a consequence, the visual presentation accompanied by interference does not yield a phonetic similarity effect because the words are never coded phonetically.

The existence of a visual-spatial code has been adduced from analogous experiments that involve visual presentation of material accompanied by visual secondary tasks (e.g., Baddeley et al., 1973). In addition, neuroimaging research has offered support for the independent existence of a short-term visuospatial system of the sort proposed by working memory (Smith and Jonides, 1999). The episodic buffer has received little research attention, and at this time no evidence is available concerning the hypothesized code for that system.

The theory of working memory continues to be developed and has provoked a good deal of research, much of it related to the nature of codes in short-term memory. The theory has nothing to say about codes stored in long-term memory, and for the structural view of long-term memory, we turn to the memory systems approach.

#### *2.07.4.1.3 Memory systems*

The paragon of modern structuralism in cognitive psychology is the idea generally known as the memory systems approach. Essentially the approach advocates the existence of multiple memory systems in both short- and long-term memory and sets a research agenda of discovering the systems and delineating subsystems. A variety of classification schemes have been proposed, and the one described here is that of Schacter and Tulving (1994; Schacter et al., 2000). Schacter and Tulving outlined a list of defining features for a system that includes the operating rules, the neuroanatomical location of the system, and the type of information stored in the system. The later characteristic is the one of interest to us.

In 1972, Tulving proposed a distinction between what he called semantic memory and episodic memory. Semantic memory stores context-free information that corresponds to knowledge. For example, semantic memory contains information such as 'St. Louis is in Missouri, tomatoes are fruit, Dick Cheney shoots at birds.' These representations are abstract in the sense that the information coded in semantic memory is not constrained by time or space. In contrast, episodic memory stores information bound by its spatial and/or temporal context. For example, episodic memory contains information such as 'I went to the pharmacy yesterday, my wife and I saw Spamalot last Friday, I was told yesterday that John does not like tequila.' Note that the information in episodic memory has a personal as well as a temporal and/or spatial reference. The information stored in episodic memory corresponds to what we normally take to be memory rather than knowledge.

Since Tulving's original proposal, additional memory systems with their associated codes have been discovered. One is the procedural system that contains representations of cognitive and motor skills. These codes are similar to the codes in semantic memory in that they are abstract but differ from semantic memory in the kind of content. The code for the procedural memory literally is the representation of how to do something, like tie your shoes. The procedural code is not readily recoded verbally (try describing how to tie a shoe without using your hands), which is very different from the code in semantic memory. Another recently proposed system is the perceptual representation system. This system contains codes representing the visual and the auditory form of words. For example, the visual form 'cat' is stored in the perceptual representation system as well as a separate code representing the sound of that visual pattern. As with the semantic and procedural codes, the codes in the perceptual representation system do not contain contextually defining information. Unlike those two systems, the perceptual representation is just that, viz., the modality-specific representation of a word or object. Finally, working memory also is included as one of the components of the system.

### 2.07.4.2 Summary of Structural Approaches

Memory codes are fundamental to the structural view of the mind in that a defining feature of any theoretical structure is the kind of code it contains. That is, the type code is one of the inherent characteristics of a system, just as skin is an inherent characteristic of mammals. The combination of system and characteristic code then is used as the principal explanation for performance. For example, consider the following situation: Subjects are asked remember a small amount of material but are prevented from rehearsing that material after its presentation and then tested within 30 s of the presentation. Memory for the material will be surprisingly poor (e.g., Peterson and Peterson, 1959). One explanation is that the test drew on short-term memory, which contains a limited duration trace, an aspect of the code contained in short-term memory. As with all metaphors used in science, the structural metaphor not only serves to explain performance but also molds the form of research. Under the structural umbrella, a prominent and respectable research activity is that of identifying and classifying the nature of codes. Thus, much of the research provoked by any of the previously mentioned structural views will be devoted to a description of the memory code. In this function, the structural notion of a memory code has been invaluable for cognitive neuroscience. As mentioned previously, most of the cognitive neuroscience of memory is devoted to identifying brain sites associated with memory phenomena – sites that then are taken to be the brain codes for the prior experience.

### 2.07.4.3 Process Metaphor

A very different characterization of memory in general and coding in particular arises if mental functioning is assumed to be analogous to a process or skill. The idea is that memory performance is determined by the mental processes operating at the time of an experience rather than by where the memory trace is stored. Craik and Lockhart's (1972) framework, levels of processing, was the seminal impetus for the processing metaphor, and in 1993 it was declared the most successful theory of learning and memory in the previous 25 years (Roediger, 1993). According to its authors, levels of processing "suggested that the memory trace could be thought of simply as the record of those analyses that had been carried out primarily for the purposes of perception and comprehension and that deeper, more semantic analyses yielded records that were more durable" (Lockhart and Craik, 1990, p. 88). Thus, levels of processing assume that the coding process focuses on either the meaning of an event or on nonsemantic properties, such as visual or phonetic features of the event. Attention to semantic features is considered deeper processing, and research has shown time and again that all other things being equal, semantic processing leads to better retention.

The gradual discovery of boundary conditions to semantic processing superiority has led to revisions to the original idea, wherein the central role of depth has been replaced by concepts such as elaborative processing (Craik and Tulving, 1975), distinctive processing (Jacoby and Craik, 1979), and sensory-semantic processing (Nelson, 1979), but the effect of Craik and Lockhart's thinking is manifested in the assumptions these revisions all share with the original view. Chief among these is that coding processes yield a memory trace consisting of qualitative features representing the event. Certain types of traces are more beneficial for retention than others; which type varies with the theorist, but in all cases memory is determined by the qualitative nature of the code. The qualitative nature of the trace is determined by the encoding processes, not by where the trace is stored, as is assumed by most structural theories.

In close temporal and spatial contiguity to Craik and Lockhart's work, a more radical version of the process metaphor began its development with Kolers' (1973) work.

In accord with levels of processing, memory systems played no role in the explanation of performance, but in addition, memory traces of the sort used by structural theories and by levels of processing were shed. The important role of memory traces as conceptual bridges between the past and present was assigned to the psychology processes brought to bear on the current event: The analytic operation of coding the experience becomes what is remembered. The implications of this shift for the concept of coding are far-reaching, as is evident in the following quotation from Kolers (1979):

> On the present view, every encounter with a stimulus elicits a different analysis from every other.... In other words, recognition is achieved by virtue of the correlation between the operations carried out on the two encounters with the stimulus event. The more similar the operations, the readier the recognition. But as nothing ever repeats itself exactly, recognition is based on the transfer of skills across occasions and partial correlation. *If the operations that are activated are themselves the record of the stimulus, then as the operations change, the representation of the stimulus also changes; there is no permanent trace of an object, nor even a fixed trace, but skill-developed and occasion-dependent representations.* (p. 383, italics added)

The position expressed here eventually would be known as proceduralism (Kolers and Roediger, 1984). The basic tenet of coding in proceduralism is that the code is the set of psychological processes engaged for perception and comprehension of an event. Levels of processing, in contrast, assumed that these processes produced a trace or code, which was stored in memory. Proceduralism adheres to a much stricter use of the skill metaphor, whereby there is no stored trace or code. After all, where is your typing skill when you are not typing or your adding skills when you are not adding? Rather than assuming a stored trace, the connection between the past and present in proceduralism is represented by the similarity of the psychological processes engaged by the present event to some operations engaged in the past. The more similarity between the two sets of processes, the greater will be the transfer. The metric of similarity includes the modality through which the events are experienced on the reasonable premise that the psychological processes of vision and audition, for example, are different. Thus, one can see that the code for a given event is quite particular and tightly bound by the processing context.

As counterintuitive as the idea is for our intuitions about memory, Kolers (e.g., 1974) offered programmatic evidence for the approach that was sufficiently persuasive to produce important progeny in cognitive psychology. Most notable of these in memory are Roediger's ideas about data-driven and conceptually driven processing and Jacoby's process dissociation theory, both of which take proceduralism's assumptions about coding as foundational.

#### 2.07.4.3.1 Data-driven and conceptually driven processing

The distinction between data-driven and conceptually driven processing emerged as an explanation for dissociations in performance on different types of memory tests. Roediger et al. (1989) argued that these dissociations reflect differences in the processing demands of differences between study/test conditions. The basic assumption is that a particular type of prior processing may be more effective for one type of test than for another. An important example for the development of the data-driven/conceptually driven distinction is the previously discussed research of Jacoby (1983). As a brief reminder, Jacoby asked people to study words under different conditions. In one condition, the words were read without any context. In another condition, the words were generated by the subjects in the context of semantic clues. On a later recognition test, the people who generated the items at study performed better than those who read them – the standard generation effect. However, if the test was to identify visually degraded words, previous reading of the word led to better identification than did previous generation.

Roediger et al. (1989) used Jacoby's (1983) work as the basis for distinguishing the coding of meaning (conceptually driven processing) and the coding of perceptual features (data-driven processing). The dichotomy between semantic and sensory-based codes is not new to our discussion, having been an important component of the stage model, the memory systems, and levels of processing. What is different is that Roediger et al. couched the distinction in processing language. The code for meaning is the psychological processes engaged to analyze the event, and the effect of this prior processing will be revealed only in future circumstances demanding similar analysis of the event. The code created by generating the word 'cat' will not facilitate future demands to read the word 'cat'. In that sense, one can appreciate Kolers' previous quotation to the effect that as the operations change, the representation of the event changes.

The distinction between data-driven and conceptually driven coding has been a powerful stimulant for research and has served an impressive role in classification and organization of memory tests (e.g., Blaxton, 1989; Rajaram and Roediger, 1993). Situations have arisen, however, that resist clean dichotomizing into data-driven and conceptually driven processing. A very simple example is the standard recognition memory test, in which one must process the test item perceptually before a decision concerning its status can be reached. On the face of it, this situation seems to require both data-driven and conceptually driven processing. The authors of the idea recognized this implication early on: "Tests may involve both types of processes. Indeed, a more useful assumption is to describe two continua, one for each type of processing, to acknowledge that these two modes of processing can be varied orthogonally" (Srinivas and Roediger, 1990, p. 390). The interesting point for our discussion of coding is the realization that characterizations of the trace for an event as exclusively perceptual or conceptual, the very assumption that caused trouble for the stage model, are too simplistic. Advocates of the data-driven/conceptually driven view avoid that mistake by assuming that the code will include both types of information in most all cases.

#### 2.07.4.3.2 Process dissociation theory

Another descendant of Kolerian proceduralism is the process dissociation framework (Jacoby, 1991). Like the memory systems and data-driven/conceptually driven ideas, Jacoby's theory was motivated largely by the challenge of understanding test dissociations. Unlike the other approaches, process dissociation explicitly disavows any effort to identify processes, codes, or systems on the basis of the type of task. Both the memory systems and the data-driven/conceptually driven schemes use the task confronting the subject to identify the type of code that will be required by that task. As research began to discover violations of the prescribed system- or process-task relationship, both the systems and the data-driven/conceptually driven approaches moved to a middle ground: the code for any given event is likely to be mixed. The same data suggested to Jacoby (1991) that these approaches cannot succeed in explaining memory phenomena. The reason is that the explanatory (predictive) power of either approach rests heavily on the ability to identify the theory-specified code representing an event. The primary means for doing so is to assume a code-task purity (i.e., a particular kind of task will recruit a particular kind of code). At best, the inability to identify task-pure codes robs these approaches of some of their precision.

Jacoby's alternative is to specify the nature of the processes as *a priori* rather than identify the operative processes on the basis of task performance. The details of the theory accomplishing this specification are beyond the purview of this chapter, but the assumption about the nature of the code is pure Kolerian proceduralism. Psychological processes are brought to bear on tasks with which we are confronted. These processes vary not only with task demands but also with both external and internal contexts, intent being an important component of the later. In this view, precisely the same process (a.k.a., code) is unlikely to be repeated, a position identical to that expressed in the italicized portion of the quotation from Kolers listed earlier. Consequently, every memory has a unique code in that no two situations engage identical psychological processes.

### 2.07.4.4 Summary of Process Metaphor

One can conceptualize cognitive activities including learning and memory as analogous to motor skills. Just as particular motor tasks require particular motor processes, so do particular cognitive tasks engage particular processes. In both cases, performance on a task is determined by prior processing as it is related to the task. That is, the effect of prior processing can be either positive or negative. For example, my racquetball game improves with racquetball practice, but my squash game deteriorates as I practice racquetball. The same is true of cognitive tasks. Although it may be that the structural metaphor can encompass all of the memory phenomena marshaled by the process camp, the differences in the metaphors are important influences on research. Three implications of the process metaphor are quite different from anything derived from structural thinking.

Perhaps the least intuitive of these implications is that the influence of the past is not carried by a permanently existing code stored in the system. If learning and memory are thought of as processes, then like typing, or for that matter digestion, memory is nowhere when you are not remembering. Within the process metaphor, the function of the memory code is assigned to transient psychological processes, and research focused on the overlap of processes from one task to another is essentially the process approach to studying the code. However, the vast amount of research sponsored by the structural metaphor aimed at describing memory systems would never occur under the auspices of a process metaphor.

A second and only slightly less counterintuitive implication of proceduralism is that abstract codes of the kind traditionally associated with knowledge do not exist. Take, for example, the following information: George Washington was the first president of the United States. An abstract code for this information would be stripped of any contextually specific aspects of prior experience with the information, such as when, where, or through what modality the experience occurred. If, however, we adopt a proceduralist's definition (i.e., the code representing an experience is the set of operations that yielded that experience), no representation would be free of context-specific content. The operations producing the experience include those sensory–perceptual processes associated with the modality of processing, and in most cases, it is reasonable to assume that other aspects of the context would influence the encoding operations. The implied lack of an abstract code poses a challenge for proceduralist's accounts of learning and use of concepts, where a concept traditionally is assumed to be distilled from, but not identical to, any particular prior experience. The difference between the abstractionist's and the proceduralist's positions is the venerable difference between rational and empirical knowledge, and it is exciting to see empirical work emerging on this important epistemological issue (e.g., Whittlesea et al., 1994; Heit and Barsalou, 1996; Hannah and Brooks, 2006).

A third implication of the process metaphor extends beyond the issue of coding and is of general importance to conceptualization of cognition. In two different senses, proceduralism is integrative, whereas structuralism leads to modularity. The first sense of integration is that proceduralism need not distinguish various cognitive processes (e.g., perception, memory, reasoning) except on operational grounds for clarity of communication. The aforementioned principles of proceduralism apply regardless of the operational classification of the process, rendering distinctions between such concepts as memory and reasoning unnecessary. The second dimension along which proceduralism is integrative is mind–body dualism. Crowder made this important point by noting that many theories explicitly distinguish between perception and cognition, which he suggests is dualism in a different guise because:

> perceptual skills are considered more legitimately bodily processes than the "mental" cognitive functions such as generation, reflection, and creativity. For example, Tulving and Schacter relegate priming to the activity of the perceptual representation system, as distinct from the episodic memory system. (Crowder, 1993, p. 143)

Taking skill as a metaphor for all cognitive processing, perceptual as well as conceptual, removes any boundary between body functions and mental functions.

## 2.07.5 Summary of Coding Processes

An enormous amount of research has been directed toward understanding coding processes and their resultant memory representations. The reason for the effort is that the memory code is viewed as the concept that carries the effect of prior experience into the present. In that capacity, the memory code will determine the similarity metric among prior events and between prior and current events. This similarity will determine the types of events that will interfere with each other as well as the effectiveness of certain kinds of cues in the retrieval of particular memories.

All the methods that have been used to infer the memory code are of necessity indirect, based on observations of behavior or brain activity, but the descriptions of the codes inferred from these methods point to three main ways in which the coding process operates. Codes can be a select portion of a complex event, in which case the representation is the portion of the event selected for attention. Codes can be a transformation in the form of the input such as the verbal coding of a picture or the organization of discrete units into a whole. Elaboration is a third form of coding, which yields a representation that contains more than was in the literal physical energy of the original experience. The code resulting from elaborative processing reflects the influence of prior knowledge on perception and comprehension of an event.

Placed in proper context, research on memory coding is an indication of the value of psychology in advancing our knowledge about fundamental questions of mental functioning. This chapter began with the assertion that the problem of knowledge, what can people know and how do they come to know it, is the impetus for coding research. The research has yielded a range of descriptions of particular types of codes that are the fodder for systematic theoretical classification. With that theoretical classification lays the promise of resolution to the perennial issues of the nature of knowledge, issues such as that between abstract, universal knowledge versus particular, contextually bound knowledge.

The resolution has not been achieved, but it is exciting to know that research in psychology has such ambitious aims.

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## References

Anderson JR (1978) Arguments for representations concerning mental imagery. *Psychol. Rev.* 85: 249–277.
Anderson JR (1983) *The Architecture of Cognition*. Cambridge, MA: Harvard University Press.
Anderson RC, Goetz ET, Pitchert JW, Schallert DL, Stevens KC, and Trollop D (1976) Instantiation of general terms. *Journal of Verbal Learning and Verbal Behavior* 15: 667–679.
Anisfeld M and Knapp M (1968) Association, synonymity, and directionality in false recognition. *J. Exp. Psychol.* 77: 171–179.
Atkinson RC and Shiffrin RM (1968) Human memory: A proposed system and its control processes. In: Spence KW and Spence JT (eds.) *Advances in the Psychology of Learning and Motivation Theory and Research,* vol. 2, pp. 89–195. New York: Academic Press.
Baddeley AD (1966) Short-term memory for word sequences as a function of acoustic, semantic, and formal similarity. *Q. J. Exp. Psychol.* 18: 362–365.
Baddeley AD (2000) The episodic buffer: A new component to working memory. *Trends Cogn. Sci.* 4: 417–423.
Baddeley AD, Grant S, Wight E, and Thomson N (1973) Imagery and visual working memory. In: Dornic PMA and Dornic S (eds.) *Attention and Performance V*, pp. 205–217. London: Academic Press.
Baddeley AD and Hitch G (1974) Working memory. In: Bower GH (ed.) *The Psychology of Learning and Memory,* vol. 8, pp. 47–89. New York: Academic Press.
Baddeley AD, Lewis V, Eldridge M, and Thomson N (1984) Attention and retrieval from long-term memory. *J. Exp. Psychol. Gen.* 13: 518–540.
Baddeley AD, Lewis V, and Vallar G (1984) Exploring the articulatory loop. *Q. J. Exp. Psychol.* 36: 233–252.
Begg I, Vinski E, Frankovich L, and Holgate B (1991) Generating makes words memorable, but so does effective reading. *Mem. Cognit.* 19: 487–497.
Blaxton TA (1989) Investigating dissociations among memory measures: Support for a transfer appropriate processing framework. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 657–668.
Bousfield WA (1953) The occurrence of clustering in recall of randomly arranged associates. *J. Exp. Psychol.* 49: 229–240.
Bower GH (1972) Stimulus sampling theory of encoding variability. In: Melton AW and Martin E (eds.) *Coding Processes in Human Memory*, pp. 85–124. Washington DC: V. H. Winston and Sons.
Bower GH and Karlin MB (1974) Depth of processing of pictures, faces, and recognition memory. *J. Exp. Psychol.* 103: 121–156.
Bower GH and Lesgold AM (1969) Organization as a determinant of part-to-whole transfer in free recall. *Journal of Verbal Learning and Verbal Behavior* 8: 501–507.
Bradley B and Mathews A (1983) Negative self-schemata in clinical depression. *Br. J. Clin. Psychol.* 22: 173–181.
Bransford JD and Franks JJ (1971) The abstraction of linguistic ideas. *Cognit. Psychol.* 2: 331–350.
Brooks LR (1967) The suppression of visualization by reading. *Q. J. Exp. Psychol.* 19: 289–299.
Challis BH, Velichkovsky BM, and Craik FIM (1996) Levels-of-processing effects on a variety of memory tasks: New findings and theoretical implications. *Conscious. Cogn.* 5: 142–164.
Calkins MW (1894) Association. *Psychol. Rev.* 1: 476–483.
Cave KR and Kosslyn SM (1989) Varieties of size specific visual selection. *J. Exp. Psychol. Gen.* 118: 148–164.
Chan JC, McDermott KB, Watson JM, and Gallo DA (2005) The importance of material-processing interactions in inducing false memory. *Mem. Cognit.* 33: 389–395.
Chase WG and Simon HA (1973) Perception in chess. *Cognit. Psychol.* 4: 55–81.
Cooper LA and Shepard RN (1973) Chronometric studies of rotation of mental images. In: Chase WG (ed.) *Visual Information Processing*, pp. 75–176. New York: Academic Press.
Craik FIM, Govoni R, Naveh-Benjamin M, and Anderson ND (1996) The effects of divided attention on encoding and retrieval processes in human memory. *J. Exp. Psychol. Gen.* 125: 159–180.
Craik FIM and Lockhart RS (1972) Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior* 11: 671–684.
Craik FIM and Tulving E (1975) Depth of processing and retention of words in episodic memory. *J. Exp. Psychol. Gen.* 104: 268–294.
Crowder RG (1993) Systems and principles in memory theory: Another critique of pure memory. In: Colling AF et al. (eds.) *Theories of Memory*, pp. 139–161. Hillsdale, NJ: Lawrence Erlbaum.
Darwin CJ, Turvey MT, and Crowder RG (1972) An auditory analogue of the Sperling partial report procedure. *Cognit. Psychol.* 3: 255–267.
Deese J (1959) On the prediction of occurrence of particular verbal intrusions in immediate recall. *J. Exp. Psychol.* 58: 17–22.
Denny EB and Hunt RR (1992) Affective valence and memory in depression: Dissociation of recall and fragment completion. *J. Abnorm. Psychol.* 101: 575–580.
Donaldson W and Bass M (1980) Relational information and memory for problem solutions. *Journal of Verbal Learning and Verbal Behavior* 19: 26–35.
Ebbinghaus H (1964) *On Memory*. New York: Dover.
Einstein GO and Hunt RR (1980) Levels of processing and organization: Additive effects of individual item and relational processing. *J. Exp. Psychol. Hum. Learn. Mem.* 6: 588–598.
Ericsson KA and Lehman AC (1996) Expert and exceptional performance: Evidence of maximal adaptation to task constraints. *Annu. Re. Psychol.* 47: 273–305.
Estes WK (1959) The statistical approach to learning theory. In: Koch S (ed.) *Psychology: A Study of a Science,* vol. 2, pp. 380–491. New York: McGraw-Hill.
Farah MJ (1985) Psychophysical evidence for shared representational medium for mental images and percepts. *J. Exp. Psychol. Gen.* 114: 91–103.
Farah MJ (2006) Visual perception and visual imagery. In: Farah MJ and Feinberg TE (eds.) *Patient-Based Approaches to Cognitive Neuroscience,* 2nd edn., pp. 111–116. Cambridge, MA: The MIT Press.
Farah MJ (1995) The neural bases of mental imagery. In: Gazzaniga M. (ed.) *The Cognitive Neurosciences*, pp. 963–975. Cambridge, MA: The MIT Press.

Fernandes MA and Moscovitch M (2000) Divided attention and memory: Evidence of substantial interference effects at retrieval and encoding. *J. Exp. Psychol. Gen.* 129: 155–176.
Fillenbaum S (1969) Words as feature complexes: False recognition of antonyms and synonyms. *J. Exp. Psychol.* 82: 400–402.
Gallo DA, Roediger HL III, and McDermott KB (2001) Associative false recognition occurs without strategic criterion shifts. *Psychon. Bull. Rev.* 8: 579–586.
Gardiner JM, Craik FIM, and Birtwhistle J (1972) Retrieval cues and release from proactive inhibition. *Journal of Verbal Learning and Memory* 11: 778–783.
Graf P (1980) Two consequences of generating: Increased inter- and intraword organization of sentences. *Journal of Verbal Learning and Verbal Behavior* 19: 316–327.
Green RT (1956) Surprise as a factor in the von Restorff effect. *J. Exp. Psychol.* 52: 340–344.
Hannah SD and Brooks LR (2006) Producing biased diagnoses with unambiguous stimuli: The importance of feature instantiations. *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 1416–1423.
Heit E and Barsalou LW (1996) The instantiation principle in natural categories. *Memory* 4: 413–451.
Henson R (2006) Forward inferences using functional neuroimaging: Dissociations versus associations. *Trends Cogn. Sci.* 10: 64–69.
Henson R (2005) What can functional imaging tell the experimental psychologist? *Q. J. Exp. Psychol.* 58A: 193–233.
Humphreys MS (1976) Relational information and the context effect in recognition memory. *Mem. Cognit.* 4: 221–232.
Hunt RR (2006) The concept of distinctiveness in memory research. In: Hunt RR and Worthen JB (eds.) *Distinctiveness and Memory*, pp. 1–25. New York: Oxford University Press.
Hunt RR and Einstein GO (1981) Relational and item-specific information in memory. *J. Verbal Learn. Verbal Behav.* 20: 497–514.
Hunt RR and McDaniel MA (1993) The enigma of organization and distinctiveness. *J. Memory Lang.* 32: 421–445.
Hunt RR, Elliott JM, and Spence MJ (1979) Independent effects of process and structure on encoding. *J. Exp. Psychol. Hum. Learn. Mem.* 5: 339–347.
Hyde TS and Jenkins JJ (1969) Differential effects of incidental tasks on the organization of recall of a list of highly associated words. *J. Exp. Psychol.* 82: 472–481.
Intons-Peterson MJ (1983) Imagery paradigms: How vulnerable are they to experimenters' expectation? *J. Exp. Psychol. Hum. Percept. Perform.* 9: 394–412.
Jacoby LL (1983) Remembering the data: Analyzing interactive processes in reading. *J. Verbal Learn. Verbal Behav.* 22: 485–508.
Jacoby LL (1991) A process dissociation framework: Separating automatic from intentional uses of memory. *J. Memory Lang.* 30: 513–541.
Jacoby LL and Craik FIM (1979) Effects of elaboration of processing at encoding and retrieval: Trace distinctiveness and recovery of initial context. In: Cermak LS and Craik FIM (eds.) *Levels of Processing in Human Memory*, pp. 1–22. Hillsdale, NJ: Erlbaum.
Jacoby LL and Goolkasian P (1973) Semantic versus acoustic coding: Retention and conditions of organization. *J. Verbal Learn. Verbal Behav.* 12: 324–333.
Jenkins WO and Postman L (1948) Isolation and the spread of effect in serial learning. *Am. J. Psychol.* 61: 214–221.
Johnson MK, Bransford JD, and Solomon SK (1973) Memory for tacit implications of sentences. *J. Exp. Psychol.* 98: 203–205.
Kahn I, Davachi L, and Wagner AD (2004) Functional-neuroanatomic correlates of recollection: Implications for models of recognition memory. *J. Neurosci.* 24: 4172–4180.
Katona G (1940) *Organizing and Memorizing*. New York: Columbia University Press.
Kimball DR and Holyoak KJ (2000) Transfer and expertise. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 109–122. New York: Oxford University Press.
Kolers PA (1973) Some modes of representation. In: Kliner P, Kramer L, and Alloway T (eds.) *Communication and Affect: Language and Speech*, pp. 21–44. New York: Academic Press.
Kolers PA (1974) Two kinds of recognition. *Can. J. Psychol.* 28: 51–61.
Kolers PA (1979) A pattern analyzing basis for recognition memory. In: Cremak LS and Craik FIM (eds.) *Levels of Processing in Human Memory*, pp. 363–384. Hillsdale, NJ: Erlbaum.
Kolers PA and Roediger HL (1984) Procedures of mind. *J. Verbal Learn. Verbal Behav.* 23: 425–449.
Kosslyn SM (1980) *Image and Mind*. Cambridge, MA: Harvard University Press.
Kosslyn SM, Ball TM, and Reiser BJ (1978) Visual images preserve metric spatial information: Evidence from studies of image scanning. *J. Exp. Psychol. Hum. Percept. Perform.* 4: 47–60.
Lockhart RS and Craik FIM (1990) Levels of processing: A retrospective commentary on a framework for memory research. *Can. J. Psychol.* 44: 87–112.
Mathews R (1954) Recall as a function of number of classification categories. *J. Exp. Psychol.* 47: 241–247.
McCabe DP and Smith AD (2002) The effect of warnings on false memories in young and older adults. *Mem. Cognit.* 30: 1065–1077.
McDermott KB and Roediger HL III (1998) Attempting to avoid illusory memories: Robust false recognition of associates persists under conditions of explicit warnings and immediate testing. *J. Mem. Lang.* 39: 508–520.
McElroy LA and Slamecka NA (1982) Memorial consequences of generating nonwords: Implications for semantic memory interpretations of the generation effect. *J. Verbal Learn. Verbal Behav.* 21: 249–259.
McDowell J (1984) Recall of pleasant and unpleasant words in depressed subjects. *J. Abnorm. Psychol.* 93: 401–407.
Miller GA (1956) The magical number seven plus or minus two: Some limits on our capacity for processing information. *Psychol. Rev.* 63: 81–97.
Morris CD, Bransford JD, and Franks JJ (1977) Levels of processing versus test-appropriate strategies. *J. Verbal Learn. Verbal Behav.* 16: 519–533.
Nairne JS (2006) Modeling distinctiveness: Implications for general memory theory. In: Hunt RR and Worthen JB (eds.) *Distinctiveness and Memory*, pp. 27–46. New York: Oxford University Press.
Nairne JS (2002) The myth of the encoding-retrieval match. *Memory* 10: 389–395.
Naveh-Benjamin M, Craik FIM, Guez J, and Kreuger S (2005) Divided attention in younger and older adults: Effects of strategy and relatedness on memory performance and secondary costs. *J. Exp. Psychol. Learn. Mem. Cogn.* 31: 520–537.
Neisser U (1967) *Cognitive Psychology*. New York: Appleton.
Nelson DL (1979) Remembering pictures and words: Appearance, significance, and name. In: Cermak LS and Craik FIM (eds.) *Levels of Processing in Human Memory*, pp. 45–76. Hillsdale, NJ: Erlbaum.
Nelson DL, Reed VS, and McEvoy CL (1977) Learning to order pictures and words: A model of sensory and semantic encoding. *J. Exp. Psychol. Hum. Learn. Mem.* 3: 485–497.
Nelson DL, Reed VS, and Walling JR (1976) Pictorial superiority effect. *J. Exp. Psychol. Hum. Learn. Mem.* 2: 523–528.
Nelson DL, Walling JR, and McEvoy CL (1979) Doubts about depth. *J. Exp. Psychol. Hum. Learn. Mem.* 5: 24–44.

Nelson DL, Wheeler JW, Borden RC, and Brooks DH (1974) Levels of processing and cuing: Sensory versus meaning features. *J. Exp. Psychol.* 103: 971–977.
Neuschatz JS, Lynn SJ, Benoit GE, and Payne R (2003) Effective warnings in the Deese-Roediger-McDermott false-memory paradigm: The role of identifiability. *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 35–40.
Newell A, Shaw JC, and Simon HA (1958) Elements of a theory of human problem solving. *Psychol. Rev.* 65: 151–166.
Newell A and Simon HA (1972) *Human Problem Solving*. Englewood Cliffs, NJ: Prentice Hall.
Ornstein PA (1970) Role of prior-list organization in a free recall transfer task. *J. Exp. Psychol.* 86: 32–37.
Paivio A (1995) Imagery and memory. In: Gazzaniga MS (ed.) *The Cognitive Neurosciences*, pp. 977–986. Cambridge, MA: MIT Press.
Paivio A (1971) *Imagery and Verbal Processes*. New York: Holt.
Paller KA and Wagner AD (2002) Observing the transformation of experiences into memory. *Trends Cogn. Sci.* 6: 93–102.
Perfetti CA (1979) Levels of language and levels of processing. In: Cermak LS and Craik FIM (eds.) *Levels of Processing in Human Memory*, pp. 159–182. Hillsdale, NJ: Erlbaum.
Peterson LR and Peterson MJ (1959) Short-term retention of individual verbal items. *J. Exp. Psychol.* 58: 193–198.
Poldrack RA (2006) Can cognitive processes be inferred from neuroimaging data? *Trends Cogn. Sci.* 10: 59–63.
Posner MI (1969) Abstraction and the process of recognition. In: Bower GH and Spence JT (eds.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 3, pp. 44–100. New York: McGraw-Hill.
Postman L (1964) Studies of learning to learn: II. Changes in transfer as a function of practice. *J. Verbal Learn. Verbal Behav.* 3: 437–447.
Pylyshyn ZW (1981) The imagery debate: Analogue media versus tacit knowledge. *Psychol. Rev.* 88: 16–45.
Rajaram S and Roediger HL (1993) Direct comparison of four implicit memory tests. *J. Exp. Psychol. Learn. Mem. Cogn.* 19: 765–776.
Roediger HL (1993) Learning and memory: Progress and challenge. In: Meyer DE and Kornblum S (eds.) *Attention and Performance XIV: Synergies in Experimental Psychology, Artificial Intelligence, and Cognitive Neuroscience*, pp. 509–528. Cambridge, MA: MIT Press.
Roediger HL and Gallo DA (2002) Levels of processing: Some unanswered questions. In: Naveh-Benjamin M, Moscovitch M, and Roediger HL (eds.) *Perspectives on Human Memory and Cognitive Aging: Essays in Honor of Fergus Craik*, pp. 28–47. New York: Psychology Press.
Roediger HL and McDermott KB (2000a) Tricks of memory. *Curr. Directions Psychol. Sci.* 9: 123–127.
Roediger HL and McDermott KB (2000b) Distortions of memory. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 149–162. New York: Oxford University Press.
Roediger HL and McDermott KB (1995) Creating false memories: Remembering words not presented in lists. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 803–814.
Roediger HL, Watson JB, McDermott KB, and Gallo DA (2001) Factors that determine false recall: A multiple regression analysis. *Psychon. Bull. Rev.* 8: 385–407.
Roediger HL, Weldon MS, and Challis BH (1989) Explaining dissociations between implicit and explicit measures of retention: A processing account. In: Roediger HL and Craik FIM (eds.) *Varieties of Memory and Consciousness: Essays in Honour of Endel Tulving*, pp. 3–43. Hillsdale, NJ: Erlbaum.
Schacter DL and Tulving E (1994) What are the memory systems of 1994? In: Schacter DL and Tulving E (eds.) *Memory Systems*, pp. 1–38. Cambridge, MA: MIT Press.
Schacter DL, Wagner AD, and Buckner RL (2000) Memory systems of 1999. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 627–644. New York: Oxford University Press.
Shannon CE (1948) A mathematical theory of communication. *Bell Syst. Tech. J.* 27: 379–423, 623–656.
Shephard RN (1978) The mental image. *Am. Psychol.* 33: 125–137.
Shulman HG (1972) Semantic confusion errors in short-term memory. *J. Verbal Learn. Verbal Behav.* 11: 221–227.
Slamecka NJ and Graf P (1978) The generation effect: Delineation of a phenomenon. *J. Exp. Psychol. Hum. Learn. Mem.* 4: 592–604.
Slamecka NJ and Fevreiski J (1983) The generation effect when generation fails. *J. Verbal Learn. Verbal Behav.* 22: 153–163.
Smith EE and Jonides J (1999) Storage and the executive processes in the frontal lobes. *Science* 283: 1657–1661.
Sperling G (1960) The information available in brief visual presentations. *Psychol. Monogr.* 74(No. 11).
Srinivas K and Roediger HL (1990) Classifying implicit memory tests: Category association and anagram solution. *J. Mem. Lang.* 29: 389–412.
Thomson DE and Tulving E (1970) Associative encoding and retrieval: Weak and strong cues. *J. Exp. Psychol.* 86: 255–262.
Titchener EB (1898) The postulates of structural psychology. *Philos. Rev.* 7: 449–465.
Tulving E (1962) Subjective organization in free recall of ‘‘unrelated’’ words. *Psychol. Rev.* 69: 34–3554.
Tulving E (1966) Subjective organization and the effects of repetition in multi-trial free recall learning. *J. Verbal Learn. Verbal Behav.* 5: 193–197.
Tulving E (1968) Theoretical issues in free recall. In: Dixon TR and Horton DL (eds.) *Verbal Behavior and General Behavior Theory*, pp. 2–36. Englewood Cliffs, NJ: Prentice Hall.
Tulving E (1972) Episodic and semantic memory. In: Tulving E and Donaldson W (eds.) *Organization of Memory*, pp. 382–404. New York: Academic Press.
Tulving E (1989) Remembering and knowing the past. *Am. Sci.* 77: 361–367.
Tulving E and Bower GH (1974) The logic of memory representations. In: Bower GH (ed.) *The Psychology of Learning and Memory*, pp. 265–303. New York: Academic Press.
Tulving E and Osler S (1967) Transfer in whole/part free recall learning. *Can. J. Psychol.* 21: 593–601.
Tulving E and Thomson DM (1973) Encoding specificity and retrieval processes in episodic memory. *Psychol. Rev.* 80: 352–373.
van Overschelde JP, Rawson KA, Dunlosky J, and Hunt RR (2005) Distinctive processing underlies skilled memory. *Psychol. Sci.* 16: 358–361.
von Restorff H (1933) Uber die Wirkung von Bereichsblidungen im Spurenfeld. *Psychol. Forsch.* 18: 299–342.
Wagner AD, Schacter DL, Rotte M, et al. (1998) Building memories: Remembering and forgetting of verbal experiences as predicted by brain activity. *Science* 281: 1188–1191.
Watkins MJ (2002) Limits and province of levels of processing: Considerations of a construct. *Memory* 10: 339–343.
Watkins OC and Watkins MJ (1975) Buildup proactive inhibition as a cue-overload effect. *J. Exp. Psychol. Hum. Learn. Mem.* 104: 442–452.
Watkins PC, Mathews A, Williamson DA, and Fuller RD (1992) Mood-congruent memory in depression: Emotional priming or elaboration? *J. Abnorm. Psychol.* 101: 581–586.
Whittlesea BWA, Brooks LR, and Westcott C (1994) After the learning is over: Factors controlling the selective application of general and particular knowledge. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 259–274.
Wickens DD (1970) Encoding categories of words: An empirical approach to meaning. *Psychol. Rev.* 77: 1–15.
Wickens DD, Born DG, and Allen CK (1963) Proactive inhibition and item similarity in short-term memory. *J. Verbal Learn. Verbal Behav.* 2: 440–445.

# 2.08 Mental Imagery

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## 2.08.1 Introduction to Imagery and Definitions of Mental Imagery

In our everyday life, during interactions with people and with the environment, a crucial role is fulfilled by the ability to maintain and to recall images (i.e., mental representations including perceptual information). Most of the time, mental images are incidentally activated, such as, for example, when we think back to people's faces or certain episodes of our life. Other times, images are easily retrieved to answer particular questions; for example, people can recall and visualize in their mind how many windows there are in their house and the color of the curtains.

Mental images have always fascinated philosophers; in fact, Greek philosophers such as Plato and Aristotle discussed mental images, the latter considering imagery crucial in both cognition and thinking. Aristotle's theory could be considered the antecedent of the modern analogical imagery view, which maintains a close relationship between perception and imagery (e.g., Shepard and Metzler, 1971; Kosslyn, 1980, 1994). In fact, according to Aristotle, a mental image is an inner representation of real objects, like a copy of real-life scenes. Moreover, medieval thinkers like Augustine and Aquinas gave a central position to imagery in their interpretation of psychological processing from sensation to imagination and memory. Similarly, the British empiricists, for example, Berkeley, Hobbes, and Hume, considered mental images as traces of sensory information. As for more recent times, it is only from the 1970s that psychology reconsidered imagery as a central topic of study (i.e., ever since the advent of cognitive psychology). In fact, behaviorists had failed to consider imagery as a serious topic for experimental investigation because it was not directly observable and thus could not be investigated with a completely objective methodology. The cognitive sciences represented a new era for research on imagery processes. Interest toward mental events was once again a central topic in psychology, and different experimental paradigms were applied to the investigation of higher cognitive processes, such as imagery. Individual reports and subjective introspective experiences were considered objects of interest for experimental psychology, and imagery was included as a legitimate topic of investigation.

In the psychological literature, various definitions and theories regarding mental images were put forward, and most of them were influenced by the interdisciplinary interests surrounding this process. According to Holt (1964), a mental image refers to all the subjective awareness experiences within a sensory modality, which are not only perceptual. Intons-Peterson and McDaniel (1991) affirmed that mental images might be produced by the interaction between visual representation and a subject's knowledge, suggesting that they are knowledge-based products. Carroll (1993, p. 277) defined imagery as "the ability in forming internal mental representations of visual patterns and in using such representations in solving spatial problems" and proposed a relationship between spatial abilities, visual perception, and imagery. Similarly, Richardson (1999) postulated that mental images are complex mental products, inner representations where information on the actual perceptual appearance of objects can be described and transformed.

Mental imagery is a private and a subjective experience because we cannot observe whether other people have a mental image nor directly know its properties. This implies that its scientific investigation depends on verbal reports and on the phenomenal experience of participants (Richardson, 1980). However, psychological investigation has tried to operationalize or give construct validity to the concept of mental image. For example, according to Paivio (1971), a mental image is defined on the basis of three kinds of operations, that is, (a) by variations in stimulus properties (e.g., high vs. low imagery value), (b) by processing instructions (e.g., instructions to imagine vs. instruction to verbalize), and (c) by individual differences in imagery ability. According to Kosslyn (1980, 1994), a mental image is not simply a phenomenal experience, but a form of internal representation in which information about the visual appearance of a physical object can be manipulated: Visual mental images correspond to short-term memory displays, which are generated from more abstract representations in long-term memory (Kosslyn, 1980; Denis and Kosslyn, 1999). However, the methodological difficulties in the study of imagery have affected a recursive debate between imagery theorists (who support an analogical or pictorial position) and propositionalists (who maintain the existence of an amodal representation, e.g., Pylyshyn, 1973).

### 2.08.1.1 Debate on the Nature of Representations

The contrast between empirical and rational theories on the acquisition and on the representation of knowledge is recurrent in the history of thinking (e.g., Aristotle against Plato, British Empiricists against Descartes in philosophy and propositionalists against imagery theories in psychology). To summarize, the propositionalists affirm that mental images are epiphenomena, having a symbolic-like format, with no sensorial properties and an explicit explanation of the relations between elements (Pylyshyn, 1973, 1981). According to propositionalists, the representations that underlie the experience of mental imagery are similar to those used in language. The second position, upheld by imagery theorists like Kosslyn (1980, 1994), holds that mental imagery representations are able to depict, not describe, objects; they are analogical representations of objects in our mind and correspond to a quasi-perceptual experience, with a specific modality format.

The initial debate focused on behavioral results such as those obtained by Kosslyn et al. (1978). In the original study, participants were required to memorize a map of an island, where a series of landmarks was drawn, then to imagine the map and to pay attention to one place (e.g., the beach). When the experimenter gave the name of a second place (e.g., the tower) participants had to imagine moving from one place to the other and to press a button as soon as they had reached the second place in their mental image of the map. The results of the study revealed that the further away the second place was from the initial place (the beach), the longer it took for participants to give the response. The conclusion of the authors was that mental images have spatial properties.

The critiques made by Pylyshyn (2002) were as follows: It is not clear whether the results revealed a property of the cognitive architecture or a property of what people know or believe about imagery functioning. Pylyshyn (1981) repeated the experiment by showing participants a map with lights going on and off at the target locations; participants were required to imagine when a light was on and to press a button when they could see it at a second place. Results did not reveal correlations between the distance on the imagined map and reaction times. Similarly, Cornoldi et al. (1996a) found that the distance effect is in relationship to the theories people have about imagery functioning. However, differently from Pylyshyn (2002), they concluded that naïve theories do not simply affect responses but also affect imagery retrieval processes (for a complete debate on these paradigms, see Denis and Kosslyn, 1999).

The debate moved into a new phase when neuroimaging began to be used to study brain activation during mental imagery (see for reviews, Cabeza and Nyberg, 2000; Kosslyn et al., 2001). During mental imagery, some functional magnetic resonance imaging (fMRI) studies showed an activation of topographically mapped brain areas depicting shapes (see Thompson and Kosslyn, 2000). Furthermore, if these areas are damaged, visual imagery is impaired (Kosslyn et al., 1999). A crucial result to reach the conclusion that imagery involves quasi-perceptual experiences would be if the same visual areas were activated when an object is perceived and when it is imagined. Despite a great number of studies carried out to investigate the involvement of primary visual cortex in imagery, the issue is still open, because results are controversial. In a series of positron emission tomography (PET) experiments, Kosslyn and colleagues found an increased blood flow in Brodmann Area 17 (primary visual cortex) during imagery activity (Kosslyn et al., 1993, 1997); however, other studies with fMRI methods suggest that primary visual cortex is not activated during mental imagery (e.g., D'Esposito, 1997; for a review, see Cabeza and Nyberg, 2000).

In a recent research, Kosslyn and coworkers (Slotnick et al., 2005) tried to disambiguate the long-standing debate on the nature of mental imagery representations and found evidence supporting the depictive view of visual mental imagery. In fact, the authors' contrasting imagery and attention retinotopic maps showed that visual mental imagery can evoke topographically organized activity in striate and extra-striate cortex, in accordance with the stringent criterion required for supporting a depictive theory, as mentioned by Pylyshyn (2002).

Alongside the two opposite positions (propositionalists vs. imagery theorists), intermediate models have been proposed. For example, mental images have been considered as being generated from long-term memory information, thus representing an intermediate format between amodal abstract representations and perceptions. The information in long-term memory would be represented in a more abstract format, whereas conscious mental images would acquire a more sensorial format (Marschark and Cornoldi, 1990). In fact, it is possible that short-term visual memories maintain perceptual detail, but during the integration of information in long-term memory, they lose part of their sensorial properties (Cornoldi et al., 1998).

### 2.08.1.2 Perceptual and Conceptual Representations: Visual Traces and Generated Images

Cornoldi et al. (1998) proposed a distinction between a visual trace, sharing a large number of characteristics with perception, and a generated image, more dependent on conceptual processes but still distinguishable from an amodal representation. In fact, not only the psychological literature but also subjective experience supports a differentiation between a visual memory based on a recent perceptual experience and a generated mental image. In synthesis, a visual trace is directly received from perception while it happens. For example, when we perceive a shape, we try to maintain it in our mind. In contrast, a generated image is derived from long-term memory information as, for example, when we try to activate an image of our previous car. If the first requires a low degree of attentional control to be kept activated, the latter requires a higher degree of control; moreover, the analogy with perception would be almost complete for a visual trace and only partial for a generated image, and a visual trace would be characterized by sensorial and phenomenic properties and a generated image by perceptual–conceptual properties. It must be noted that a visual trace is also different from a perceptual experience and that, even after short time intervals, a visual experience can be affected by long-term memory reconstructive processes and thus approximate the features of a generated image. The well-known experience of the inability to remember well-known patterns (e.g., the shape and colors of a common banknote, see the example of a 20-euro piece in Figure 1) is common to mental images but also concerns recent visual traces.


**Figure 1** People are not able to accurately remember the visual appearance of objects, even if they are frequently exposed to them.

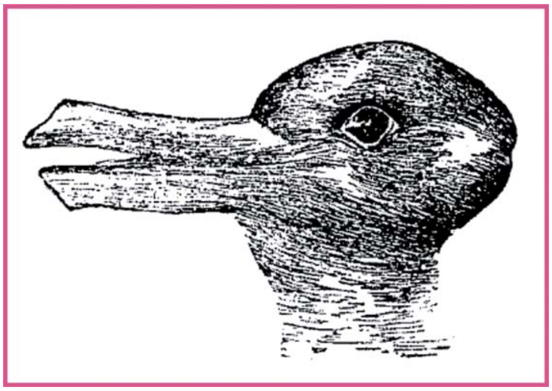

**Figure 2** The reversal of a mental image is particularly difficult but can be facilitated by the prevention of verbalization.

The distinction between a visual trace and a generated image can be also used to explain the phenomenon of verbal overshadowing, or the difficulties people meet in the reversal of mental images (Cornoldi et al., 1996b). According to Brandimonte and colleagues (Brandimonte et al., 1992a; Brandimonte and Gerbino, 1993), verbal recoding of visual stimuli occurs almost automatically when pictures are easily nameable; the verbal recoding uses long-term memory knowledge and influences the image of an ambiguous visual stimulus, determining the verbal overshadowing effect. However, if verbalization is prevented, the visual trace still maintains its perceptual properties. If you look at the picture presented in **Figure 2** and then close your eyes, you will explore the experience of a well-established image that cannot be easily reverted. If, for example, a person has in mind the image of a rabbit, that person will have difficulty visualizing a duck, and vice versa.

## 2.08.2 Different Kinds of Mental Images

Given the fact that mental images are extensively present in human life and respond to different functions, it is not surprising that they appear heterogeneous and may be differentiated. The literature on imagery has proposed a series of taxonomies among different kinds of imagery representations. Richardson (1969), for example, proposed a classification of mental images considering their different properties along the following dimensions: conscious control, phenomenological quality, intentional content, spatial location, and mode. For example, memory images were defined as conscious control phenomena with a quasi-perceptual quality, content related to experience without spatial location and with a potentially amodal format. It is noteworthy that at a higher cognitive level, a distinction can be made between mental images derived from memory and images derived from the imagination. The first refers to all images that we could evoke from memory, such as the image of the Eiffel Tower in Paris. Memory images could differ in vividness, clarity, details, colors, or multisensorial properties. Furthermore, they can be distinguished from fantasy images, created by combining elements stored in memory in new ways, as, for example, in the image of a flying horse. In fact, the creation of integrated images obtained by combining together single images represents a typical mental imagery situation, derived from the classical mnemonic tradition showing that interactive images facilitate the retrieval of an element if the other element is available. **Figure 3** presents an example of interactive image created with the support of fantasy. If the image of a rainbow and the image of a guitar must be integrated in a single interactive image, one could, for example, imagine a natural-looking guitar and a rainbow illuminating it.

The distinction between images from memory and those from the imagination is not rigid because images from memory are not exact reproductions of the equivalent perceptual experiences, whereas fantasy images are created on the basis of features derived from visual experiences. A related distinction refers to common and bizarre images. The first type represents objects, as we know them in the real world; in contrast, the latter are impossible and strange

**Figure 3** People trying to include in a single interactive image the images of a guitar and a rainbow could use fantasy to create an effective original representation.

representations of an object. Examples of bizarre images could be a dog smoking a cigar and a man chewing a bone, whereas the corresponding more common image would be a man smoking a cigar and a dog chewing a bone. This distinction has memory implications and has been the basis of mnemonic art. Cornoldi et al. (1988) found that bizarre representations improved memory recall if subjects could evoke the kind of image they wanted. Further studies (Einstein et al., 1989) reported that recall can be influenced by the distinctiveness of materials. They found that in a list of words where all the stimuli were imagined in the bizarre modality, recall was no better than when using common images. When the bizarre and common mental images were generated alternatively in the same list of words, however, the bizarre images produced a better memory performance, indicating that bizarreness *per se* does not produce superiority in memory but needs to be accompanied by another factor, such as distinctiveness.

Other classifications are more focused on the spatial properties of layouts. For example, Kosslyn (1987) distinguished between exact metric coordinates and memory for the relative relation between objects (i.e., coordinate vs. categorical representations; see also Lansdale, 1998). Studies regarding the specialized involvement of different brain structures show that the right hemisphere is important in processing metric spatial information, whereas the left hemisphere participates in processing relative spatial relations (Kosslyn et al., 1989). Other classifications of spatial images refer to the type of processing (sequential vs. simultaneous), to the reference center (egocentric vs. allocentric), and to personal space (peripersonal vs. extrapersonal).

### 2.08.2.1 General, Specific, Contextual, and Episodic-Autobiographical Images

Can mental images also represent general concepts? The existence of general and prototypical images is an ancient topic of debate. We know that the ability to create a universal or prototypical representation from the analysis of particular cases is a fundamental process in knowledge and conceptual development, but we do not know whether this representation can assume an imaginal format. Radical empiricists (Locke, Hume, Berkeley) denied the existence of general images by arguing that mental images are always based on the representations of specific objects that have been experienced, whereas a general term evokes an abstract idea. From this position two different interpretations developed: one affirming that general images representing the essential properties characterizing the general term (such as a prototypical representation) can be generated, and the other suggesting that general terms are either abstract or refer to an exemplar representation. The distinction between general, specific, contextual, and episodic-autobiographic mental images embraces the first option. The distinction has received support in recent years by cognitive (Cornoldi et al., 1989; De Beni and Pazzaglia, 1995; Helstrup et al., 1997) and neuro-anatomical data (Gardini et al., 2005). An example of a general image may consist of a skeletal representation of the main features of a bird including both coordinate and categorical spatial information. A specific image of a bird should be a particular exemplar of the category (e.g., a canary); moreover, a contextual image refers to an image in which the object or the exemplar is inserted within a context, for example, the canary in the cage. Finally, episodic-autobiographical images correspond with images of single life-episodes connected with an object and having a specific self-reference, for example, my canary escaping from its cage during a sunny day of May. Episodic-autobiographical images involve the retrieval of available episodic traces resulting from autobiographical events. The retrieval of autobiographical memories, even in the absence of specific instructions, seems strictly associated with the activation of mental images (Brewer, 1988).

Cornoldi et al. (1989) investigated the relationship between the generation of different kinds of mental images and memory recall performance. By comparing memory performance for general, specific, and autobiographical mental images, they found that the recall of general and specific mental images did not differ, but autobiographical mental images produced a better recall performance with respect to general and specific ones. De Beni and Pazzaglia (1995) distinguished between self-referred mental images within the personal autobiographical context, in which an individual imagines himself or herself together with the object without a precise episodic reference, and episodic-autobiographical images, representing a specific episode of the subject's life in relation to the object. Episodic-autobiographical mental images increased memory performance with respect to the contextual images but required longer generation times compared with other image categories. This finding could be explained by the fact that the generation of this kind of image requires the previous generation of a general image. It could also be explained by the fact that the search of a particular episode related to the object must take place, or it might be a result of the richness of details of this kind of image.

According to Cornoldi and coworkers (Cornoldi et al., 1989; De Beni and Pazzaglia, 1995) (see **Figure 4**), the mental image generation would start with the retrieval of a global shape information of the object (which can be used to generate a general image) and be subsequently enriched with details, for example, those of a particular exemplar belonging to the category of an object, or contextual information when an object is imagined in a particular context or with reference to characteristics of a familiar type of an object, thus creating the conditions for generating, respectively, a specific and a contextual image. In contrast, the generation of episodic-autobiographical mental images would undergo a different generation process directly involving the retrieval of the image from the episodic-autobiographical memory store.

In an fMRI study, Gardini et al. (2005) provided anatomical support for the results repeatedly observed in cognitive studies. The researchers, in fact, investigated the neural correlates of general and specific mental images from concrete nouns. Results showed different brain activities for both types of images; in particular, general images activated right frontal areas to a greater extent than specific images, whereas specific ones mainly activated the left-superior frontal region and the right thalamus, demonstrating that general images involve brain areas associated with the generation of global images differently from the specific images, requiring additional support from areas in charge of retrieving visual details.

## 2.08.3 Models of Mental Imagery and Memory

Most of the authors studying imagery agree with the idea that not only do the generation and the recall of mental images involve memory systems, but also their maintenance and transformation require temporary systems or subsystems of memory devoted to the treatment of visual and spatial information.

In the following paragraphs, we focus on three different approaches to the relationship between mental imagery and memory. We describe the models of Paivio and Kosslyn, and we discuss the potential role played by the visuospatial working memory system in maintaining and elaborating visual and spatial representations.

### 2.08.3.1 Paivio's Dual-Code Theory

To explain the effectiveness of imageability in predicting memory performance, Paivio (1971) proposed two different categories of processes that people can use when they encode information: images and verbal processes. He proposed studying mental images by observing the influence of imagery on memory performance, starting with a series of studies on nouns

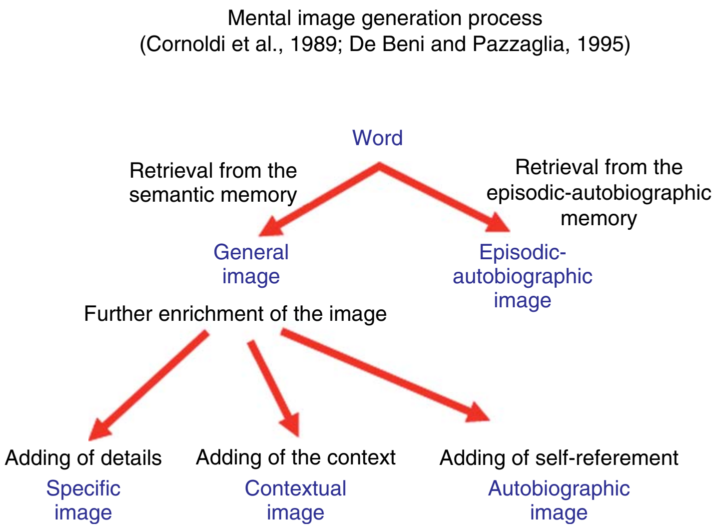


**Figure 4** The generation process of mental images (Cornoldi et al., 1989; De Beni and Pazzaglia, 1995).

and paired-associates recall. Paivio et al. (1968) examined the implications of different indexes of verbal stimuli such as meaningfulness (i.e., the number of verbal associations that a word would elicit in a given period of time), concreteness, the extent to which words refer to a tangible object, imagery value (which refers to the ease or difficulty with which words prime a mental picture), and familiarity for memory performance. Results obtained by Paivio et al. (1968) demonstrated that imagery value and concreteness were strongly related to recall, and meaningfulness and familiarity did not produce an effect on recall when the imagery value was controlled for. A particular result, concerning paired-associate recall, was that concrete-abstract pairs were recalled better than abstract-concrete pairs. The result was interpreted on the basis of the assumption that a prior image can represent an appropriate imaginal tag for subsequent information.

Paivio (1971) proposed a dual-coding theory of mental processing (see a schematic representation of the theory in **Figure 5**). The theory assumes that cognitive behavior is mediated by two independent systems specialized for encoding, transforming, storing, and retrieving information. The verbal system is responsible for the encoding and processing of verbal material and the nonverbal for encoding nonverbal input, such as images. The kind of encoding that a stimulus undergoes depends on three types of variables, that is, the nature of the material (high vs. low imagery value), the instructions given to the participants, and their imagery abilities. Paivio's model (1971, 1978) identifies three levels at which information might be processed. The first is the representational level, where the sensory trace activates the appropriate symbolic representation in long-term memory: The logogens are the basic units in long-term memory for verbal stimuli, whereas the imagens represent the basic units for imagery material. The second is the referential level, where symbolic representations in one system activate corresponding representations in the other system. These interconnections are assumed to be involved in naming objects or in creating the image of an object. In particular, referential connections between the two processes are activated when one kind of information (verbal or imagined) activates the other system. In this case there is double encoding. According to the theory, nouns with high imagery value are subjected to double encoding. "The increased availability of both codes increases the probability of item recall because the response can be retrieved from either code" (Paivio, 1971, p. 208). Finally, the associative level involves associative connections among both verbal representations and images.

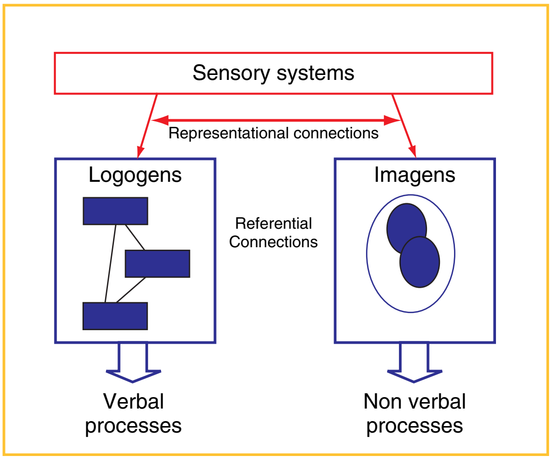


**Figure 5** A graphic representation of Paivio's (1971) Dual-Codes Theory.

### 2.08.3.2 Kosslyn's Visual Buffer

Kosslyn (1980, 1994) proposed a computational model of image generation and provided a description of the functional structures supporting this process. His model is valid for both imagery and high-level visual perception, considered to share structures, functions, and properties. Imagery is a multicomponential process, involving a series of different processes, like image generation, maintenance, inspection, and transformation. Mental generation involves the activation of an image using long-term memory information, inspection of the different parts of an image, and arrangement of the details of an image (Kosslyn et al., 1992, 1995). Mental images do not correspond to simple visual memories but are the result of a multicomponential process that assembles the different parts together and generates a new representation.

Kosslyn's model (1980) was created based on an analogy with computer graphics. Computer graphic files store information in a compressed and nonpictorial form; when they are displayed, they are translated into a mathematical map (bitmap), which specifies the color of each pixel (tiny dot) on the screen. Kosslyn suggested the involvement of two kinds of deep representations: image files containing information regarding the perceptual characteristics

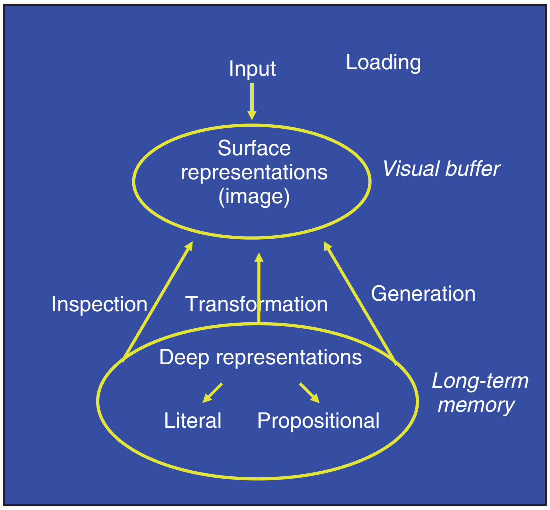


**Figure 6** Schematic representation of the interaction between long-term memory and visual buffer (Kosslyn, 1980).

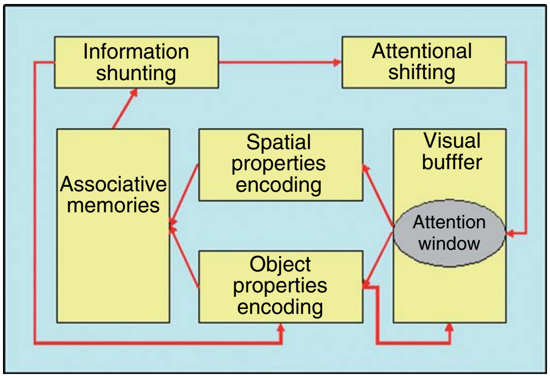


**Figure 7** Processes interacting with the visual buffer (Kosslyn, 1994).

of the skeletal image of objects, and propositional files containing abstract descriptions of objects and their parts expressed in a propositional format (see a schematic representation of the model in **Figure 6**).

Mental imagery activity can be distinguished in a series of processes. For example, the PUT process arranges parts into an image, the FIND guides the top-down search in associative memory, and the PICTURE is responsible for the activation of stored visual representations. However, a different set of processes is hypothesized to be involved in the inspection and transformation of images: REGENERATE refreshes and sharpens the existing images, LOOK FOR searches for a named part within the existing images, SCAN repositions the image by means of a linear transformation, ZOOM increases the resolution of the image, and so on. A critical component of Kosslyn's model is the Visual Buffer, which is considered to be a short-term memory system with spatial properties ($x$, $y$, $z$ coordinates, adjacent cells, etc.) located in the occipital lobe. In fact, the images are generated in the visual buffer either on the basis of information loaded by perception or on the basis of information stored in long-term visual memory (see **Figure 7**). In 1994, Kosslyn revised the model in his book *Image and Brain*, addressing the importance of seven basic components:

- The visual buffer, which holds spatially organized patterns of activation;
- The attention window, which focuses on the information in the visual buffer selected for further processing;
- The object properties encoding system, analyzing the physical properties of an object;
- The spatial properties encoding system, which analyses the spatial location of an object;
- The associative memory, containing information about the physical and conceptual properties of the objects;
- The information shunting, which uses stored information to collect further information about an object with top-down processes; and
- The attention shifting mechanism, which shifts the focus of attention from a specific location to a different one.

### 2.08.3.3 The Visuospatial Working Memory Approach

A partially different approach to imagery was adopted by other researchers, based on the idea that there is a memory system involved during the generation, maintenance, and manipulation of visual information and mental images. The visuospatial working memory (VSWM) approach (Baddeley, 1986; Logie, 1995) to imagery shares many characteristics with the visual buffer system postulated by Kosslyn (1994). However, experimental studies and research paradigms within this framework have followed different directions. The first studies with implications for the link between visual imagery and VSWM were carried out by Brooks in the late 1960s. In particular, in a 1968 study, participants were required to visualize a block capital letter and, following its contour, to answer 'yes' if the corner they mentally followed was on the bottom or the top of the figure and 'no' if it was inside the figure. Moreover, participants could

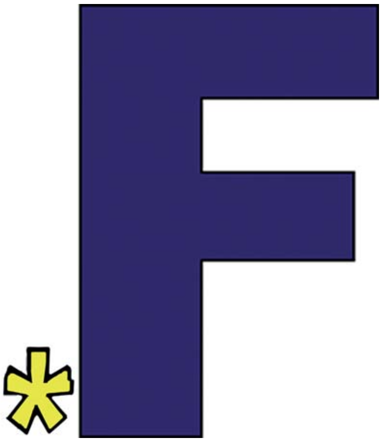

**Figure 8** An example of a mental imagery scanning task used by Brooks (1968): People are invited to mentally move along the contour of a capital letter and decide about the properties of its corners.

respond either vocally or by pointing to the letters Y and N on a sheet (see an example in **Figure 8**).

Starting from the bottom left-hand corner (indicated by the yellow asterisk) and going in the direction of the arrow, the correct responses would be: yes-yes-yes-no-no- and so on. Brooks (1968) observed that participants performed worse when responding by pointing to the letters on a sheet than when giving a verbal response, whereas the opposite happened when they had to scan a sentence rather than an image. Brooks concluded that the visualization of a block capital letter involves different cognitive resources than those used to point to printed words on a sheet. These results were consistent with the view that there is a specialized cognitive system able to process visual inputs and to generate and retain images.

The original working memory model proposed by Baddeley and Hitch (1974; Baddeley, 1986) is a nonunitary system comprising three separate components. The central executive has attentional functions and coordinates the activities of the two slave systems, the phonological loop, which maintains and processes verbal information, and the visuospatial sketchpad, in which visual and spatial information are maintained and processed by two different, but complementary, visual and spatial subcomponents (Della Sala et al., 1999). Salway and Logie (1995) attempted to examine the role of working memory and of VSWM, in particular in imagery tasks, by using several kinds of interferences on a single main imagery task. Specifically, they analyzed the effect of random generation (usually interfering with the central executive component), articulatory suppression (interfering with the phonological loop), and spatial tapping (damaging VSWM) on the performance of the Brooks matrix and a verbal task (1968). Participants were asked, in one condition, to imagine placing consecutive numbers in consecutive squares of a visualized matrix; in the second condition, they had to retain a sequence of consecutive words, for example, ‘good, bad, slow,’ and so on, placing them in a set of nonsense sentences that were to be retained without the use of any form of visual image. Results showed that articulatory suppression damaged the second (verbal) condition, that spatial tapping disrupted the first (spatial) condition, and that random generation interfered with both tasks in an important way. In 1995, Logie suggested a revised model of the VSWM involving a passive visual store (i.e., the visual cache) and an active rehearsal mechanism (i.e., the inner scribe). The visual cache provides a temporary store for visual information (color and shape), whereas the inner scribe handles information about movement sequences and provides a mechanism by which visual information can be rehearsed in working memory.

Within the classic multicomponent model of working memory, there is a debate as to whether mental imagery, having a specific visuospatial format, involves a working memory component, which maintains the specific properties of the information (i.e., the visuospatial sketchpad) or whether it also requires central processes, such as those involved in the central executive system. In the modified view of VSWM (e.g., Logie, 1995), in fact, the generation of an image appears to be the prerogative of the central executive, whereas the retention of its visual and spatial properties may be the responsibility of a temporary store, such as the VSWM system.

On this basis, we could also wonder whether there is a potential overlap between the concepts of VSWM and Kosslyn’s visual buffer. From Logie’s point of view, if the central executive is responsible for imagery generation and manipulation, it would also host the visual buffer controlling the operations involved in imagery maintenance. Kosslyn’s processes acting on the contents of the visual buffer such as GENERATE, ZOOM, SCAN, and so on, could be seen as procedures activated from long-term memory and also operated by the central executive. However, in this case, specific modal processes, in Kosslyn’s model clearly attributed to a specialized system, would be included in the amodal activity of a Central System. Moreover, the visual buffer would contain the visual properties of the image, the information about its location, and any semantic information associated with the image, but these operations would better match the operations of the visuospatial component of working memory.

Within this context, Bruyer and Scailquin (1998), using the dual-task paradigm, analyzed which working memory component is involved in the generation, maintenance, and transformation of mental images, demonstrating that both spatial tapping and random generation interfere with the generation of mental images, but only spatial tapping damages the maintenance of mental images, whereas random generation produces major interference on the transformation (i.e., rotation) of mental images. The difficulties in associating mental imagery with a specific working memory component could be overcome within a continuity model, which assumes that control can be involved at different degrees. In this framework, the VSWM processes may be distinguished according to the degree of controlled activity (see **Figure 9**); in particular, at a lower level, a simple recall of previously acquired information is required, whereas at the higher level, an elaboration of information to produce an output different from the originally presented stimulus is involved (Cornoldi and Vecchi, 2000, 2003). According to this view, a plausible specification of the imagery tasks along the continuum could involve maintenance, inspection, generation, selection, combination, and transformation, respectively ordered on the basis of the active control required (see Cornoldi and Vecchi, 2003).

Another crucial issue in VSWM concerns the nature of the components and of the type of representation maintained in memory. In fact, although there is converging evidence supporting the multicomponential nature of VSWM, there is no agreement on the number and identity of its components. A great number of neuroanatomical data, starting from the work of Ungerleider and Mishkin (1982), has supported the distinction between a spatial and a visual component, for example, by focusing on a where system or on a dorsal stream, processing spatial information, and on a what system or on a ventral stream, processing the features of perceived objects. Another fractionation in VSWM processing was suggested by Pickering et al. (2001), who distinguished between a static format of the generated representations (e.g., a matrix in which locations are presented simultaneously) and a dynamic format (e.g., a matrix in which locations are presented one at a time). A similar distinction was made also by Pazzaglia and Cornoldi (1999) between spatial-sequential and spatial-simultaneous processes: A spatial-sequential task requires recalling spatial positions presented in a sequential format, whereas in a spatial-simultaneous task, participants have to recall positions presented simultaneously. Pazzaglia and Cornoldi (1999) distinguished between these two spatial components and a visual one in which participants have to memorize objects with different shapes, colors, and textures.

## 2.08.4 Paradigms in the Study of Mental Imagery and Memory

Mental images are mental representations, which, just like thoughts, are not directly observable. As Richardson (1969) stated in the early days of the

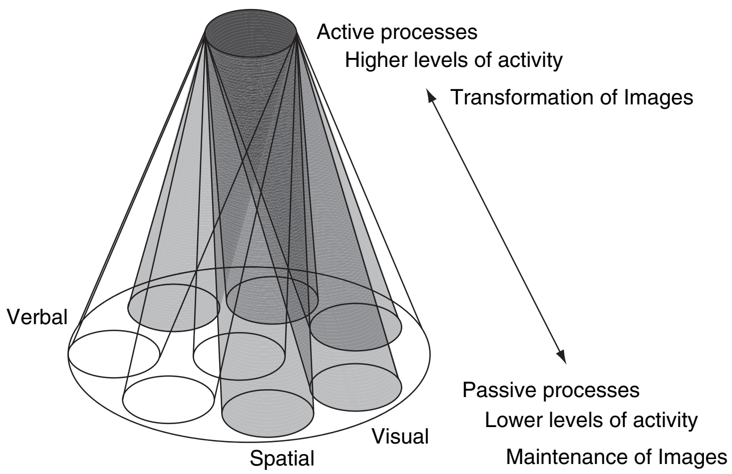


**Figure 9** The continuity model of working memory: Mental imagery involves different portions of working memory differentiated according to the type of content and the degree of control (Cornoldi and Vecchi, 2003).

renaissance of research in this area, the problem regarding mental image investigation is to find a valid method to measure imagery. In fact, from the early days of cognitive psychology, this problem has been at the center of psychological questions concerning imagery. In the present state of research, different methodologies have been developed and applied to the imagery domain, offering the possibility of further investigating this phenomenon.

### 2.08.4.1 Cognitive Paradigms of Mental Imagery Processes

Within cognitive psychology, imagery has been investigated mainly in two different ways. The first examines mental imagery as a dependent measurable variable. It studies qualitative and subjective aspects of imagery and the extent to which mental images are similar to the physical objects that are being imagined. The latter concerns the use of mental images as independent variables (manipulated by researchers) in which observable aspects are reflected in behaviors, and especially in the performance obtained by participants (Richardson, 1999). In this paragraph we focus on the direct study of imagery processes, whereas in subsequent paragraphs, we examine the implications of two main manipulations of variables related to imagery (i.e. materials and abilities).

Studies directly focused on mental imagery representations and processes have used a large range of different paradigms. A few of them have been based on the examination of the subjective imagery experience, as, for example, when people are invited to rate the vividness, or other properties, of their mental images. For example Cornoldi et al. (1992) studied which characteristics influence a vividness judgment; Baddeley and Andrade (2000) examined which manipulation depresses mental imagery, inferred by decreases in the experience of vividness.

A problem with the use of subjective experience ratings is that they are affected by the criterion people use to decide whether or not their image is of a high quality. Since Galton's (1883) first started using vividness ratings to find people with different imagery abilities, the problem has been to decide to what extent vividness ratings describe differences in representations and to what extent they describe differences in criteria. For this reason, the majority of studies focusing on the properties of mental images have also used more objective criteria, such as time, effects of the experimental manipulations, verbal descriptions of the results of imagery processes, drawings, and external ratings (for a review, see Pearson et al., 2001). For example, in the mental pathway task, people are invited to imagine a matrix with a series of cells (e.g., a simple 5 × 5 board), imagine following a pathway on the board in correspondence with the verbal instructions given (go left, down, etc.), and point, on request, to the position reached at the end of the instructions on a corresponding blank matrix. This task has been particularly successful in studying the strengths and deficits of mental imagery processing in totally congenitally blind individuals (e.g., Cornoldi et al., 1991).

The chronometric study of mental imagery has produced the main experimental paradigms in the field. The most popular paradigm is surely represented by the so-called mental rotation tasks, derived from the traditional psychometric literature on spatial abilities testing, requiring a decision of whether two figures are differently oriented examples of a single figure, or if one of them is actually different (typically its mirror image) from the other. In a series of very influential studies, Shepard and coauthors (e.g., Shepard and Metzler, 1971) reconsidered the method and manipulated the angular variation between the two pictures (see examples in **Figure 10**). They found that the time necessary for giving a response was a function of the rotation angle, showing how the decision was not based on a consideration of the properties of the object (feature $x$ is on the right of feature $y$, feature $z$ is above feature $y$, etc.), which would not have been affected by the rotation angle but was based on a process of mentally rotating one figure to see whether it perfectly matched the other one.

There are many other examples of chronometric studies of mental imagery. For example, in the preceding paragraphs, we provided examples of image generation tasks, such as images generated from a verbal label, and mental scanning tasks (e.g., scanning an island or a capital letter). In fact, in the popular taxonomy of mental imagery processes, generation, scanning (and inspection), and transformation represent three classic cases. A fourth case is

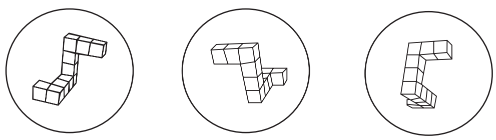

**Figure 10** Examples of pictures used for a mental rotation task: People must decide as quickly as possible if the two figures are identical or mirror images.

imagery maintenance, which can be studied either with the classic paradigms of visual memory or with reference to subjective experience (people are invited to press a button when they realize their image is vanishing).

In the field of imagery transformation, the quality of the image can be directly derived from the verbal response of the individual. For example, in a mental subtraction task, people must generate an image from the visual exposure of a drawing and then a subsequent image from the visual exposure of a part of it; their task is to subtract the second image from the first and report the verbal label of the resulting image (see **Figure 11**). Brandimonte et al. (1992b) found that the performance in this task is facilitated by the block of verbalization.

Other studies focused on different types of mental synthesis, where participants are required not only to maintain and combine different images but also to produce a different image unrelated with the single primitive images. This particular case, given the novelty and the potential originality of the final result, has also been considered an example of creative imagery. Finke and his colleagues (Finke et al., 1989) asked subjects to carry out a series of transformations on imagined figures mediated by verbally presented instructions. The transformations were designed so that the final pattern would resemble a familiar object, as in the following example of the task: Imagine a B, now rotate the B 90 degrees to the left, then add a triangle below the rotated B, and finally report what the resulting pattern looks like (see **Figure 12**).

A different and more recent example of an imagery transformation task was suggested by Vecchi and Richardson (2000), who devised the jigsaw puzzle test, considered by the authors as an active VSWM task, because participants must hold in mind the arrangement of the puzzle pieces and actively mentally manipulate their combination. In fact, the task requires that the puzzle be solved by moving the pieces only mentally, without actually touching or moving the pieces in question (see an example in **Figure 13**). Drawings represent common, inanimate objects derived by Snodgrass and Vanderwart (1980), with a high value of familiarity and of image agreement. Each puzzle is numbered, and participants give their responses by writing down the corresponding number of each piece on a response sheet.

The study of imagery processes can also be based on a fractionation of complex processes into more simple ones and on the individuation of measures tapping the most simple components, as illustrated by a series of studies by Postma and coauthors. In an analysis of memory for locations, Postma and De Haan (1996) separated the object location memory into three processes: the first process requires encoding metric information and the coordinates of a particular object located in the environment; the second process, called object-location binding, requires linking the object's identity to its position; and finally, the last process integrates the first two mechanisms and combines metric information with object identity and location (Kessels et al., 2002a,b).

**Figure 11** Examples of stimuli used for mental subtraction tasks: People, after exposure to the visual stimuli, must imagine the subtraction of the second part from the first and decide which is the resulting pattern (in this case a fish, a papillon, and a cloud).

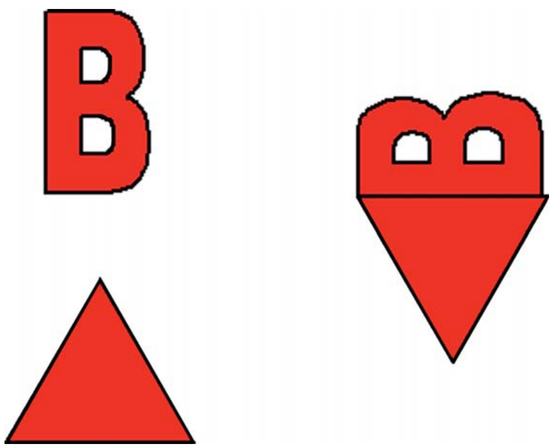

**Figure 12** Example of a creative synthesis task.

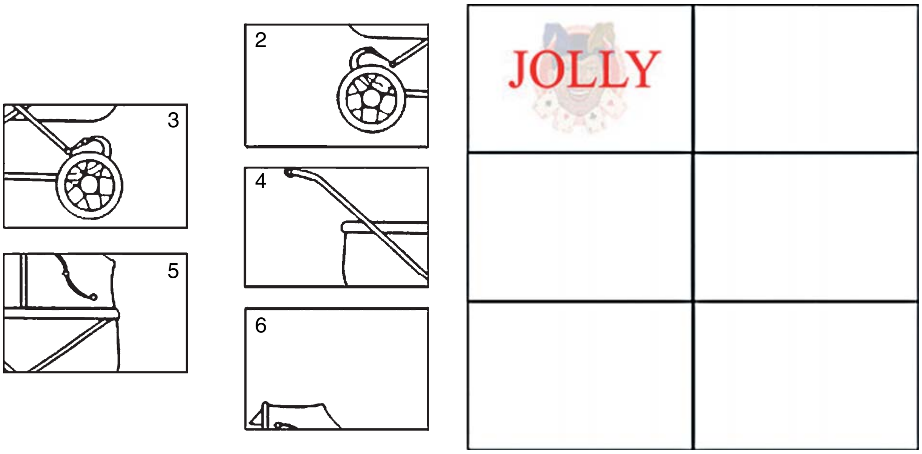


**Figure 13** Example of an item derived from the jigsaw puzzle test (adapted from Vecchi and Richardson, 2000).

### 2.08.4.2 Neural Implications

Neuropsychological paradigms have also been useful in the study of visuospatial imagery. They offer data that have increased, in many respects, our knowledge of mental imagery processes and representations. In particular, the study of single cases has revealed important dissociations and relationships. For example, Bisiach and Luzzatti (1978) reported evidence that a unilateral neglect disorder, which usually causes patients to ignore the left half of the visual field, can also result in deficits in mental imagery. They offered the example of Milan's famous Piazza del Duomo: A patient with an unilateral neglect in front of the cathedral will typically ignore the left part of the square, but – in the case of Bisiach and Luzzatti's patient – the same experience happened in the area of a mental imagery representation. In fact, invited to imagine being in front of the cathedral, the patient was not able to describe its left part. This difficulty was not related to a preceding perceptual difficulty, nor to the particular characteristics of the square, because – when invited to imagine the square giving his back to the cathedral – his imagery block involved the other side of the square (i.e., the side accurately described when facing the cathedral).

Deficits can also be purely confined to visual imagery (Beschin et al., 1997). Farah et al. (1988) reported the case of a patient who had perceptual abilities and object recognition preserved. He was also able to copy drawings correctly and to draw objects from memory, but he could not correctly answer sentences requiring imagery for verification, for example, "An elephant is larger than a mouse." Goldenberg (1989, 1992) demonstrated that patients with left temporo-occipital lesions were unable to take advantage of imagery instructions in verbal learning tasks.

The study of severe neuropsychological patients has been integrated with the study of groups of individuals hypothesized, for different reasons, to have specific difficulties in visuospatial working memory or in mental imagery tasks (for a review, see Cornoldi and Vecchi, 2003). Examples of these groups are blind individuals (e.g., Cornoldi et al., 1991; Cornoldi and De Beni, 1988), children with nonverbal/visuospatial learning disabilities (Cornoldi et al., 1999; Cornoldi and Guglielmo, 2001; Mammarella and Cornoldi, 2005), elderly people (Vecchi and Cornoldi, 1999; Richardson and Vecchi, 2002), and individuals with specific genetic syndromes (Lanfranchi et al., 2004).

With the development of more sophisticated brain-mapping techniques, the study of imagery has taken further steps forward. In fact, from the pioneering work of Roland and Friberg (1985), who studied the variations of cerebral blood flow on the basis of the visualization of familiar routes, a great number of imagery studies have been carried out with neuroimaging techniques. Some of the questions research has tried to answer are: How do differences in brain activation inform us about the nature of different kinds of imagery? What kinds of brain areas are activated during generation, maintenance, and transformation of mental images? Does mental imagery share common cortical structures with perception, memory, or motor control?

Neuroimaging methods can be classified into two main groups: electromagnetic techniques, such as MEG (magneto-encephalography) and ERPs (event-related potentials), which have excellent temporal resolution but poor spatial resolution, and techniques, such as PET and fMRI, which have good spatial resolution and coarse temporal resolution. It is noteworthy that although neuroimaging techniques can identify regions associated with a cognitive task, they cannot determine which of these regions are crucial for performing the task. For this reason, neuroimaging findings may be complemented with data provided by experimental and neuropsychological methods.

A central issue in the field of imagery is whether those visual areas involved when an object is perceived are also involved when an object is imagined. For example, Kosslyn's theory (1994) predicts activation during mental imagery activity in early visual processing regions (i.e., striate and extrastriate cortex). A series of experiments by Kosslyn and colleagues (Kosslyn et al., 1993, 2001; Kosslyn and Thompson, 2003) provided support for similarities between visual perception and visual imagery; other studies, however, have suggested that primary visual cortex is not activated during visual imagery (Roland and Gulyas, 1994; D'Esposito et al., 1997; see Cabeza and Nyberg, 2000 for a review). Roland and Friberg (1985) asked subjects to visualize the successive view along a route in a familiar environment. The task induced blood flow increase in the superior prefrontal cortex and, in particular, in the superior occipital cortex, the postero-inferior temporal cortex, and the postero-superior parietal cortex. These associative regions are also activated during processing of visual information. However, the authors did not find an activation of the primary visual cortex. According to Kosslyn et al. (1995), the right hemisphere is responsible for generating mental images from memory, whereas the left hemisphere is advantaged in the generation of visual mental images (see also Trojano and Grossi, 1994).

Charlot and coauthors (1992) selected high- and low-imagery participants and involved them in a task requiring the conjugation of abstract verbs (verbal task) and in a mental exploration of a memorized spatial configuration (imagery task). Their results revealed different patterns of activation for high (left-sensory motor cortex in the verbal task and left temporo-occipital cortex in the imagery task) and low imagers, who showed less differentiated increase of their cerebral activity. In Mellet et al.'s (1995) study, participants were required to inspect and memorize a map of an island with six landmarks. The cerebral blood flow was recorded as the participants performed either perceptual (the subjects were shown the map and asked to scan from landmark to landmark) or imaginal scanning of the map (performing a mental scan without looking at the map). The results revealed a common network of cerebral areas, in particular, bilateral superior external occipital regions, reflecting the processes involved in the generation and maintenance of visual images, and the precuneus (left internal parietal region), reflecting the scanning process. In this study, the parietal regions were involved in an imagery process with a spatial component. This latter result is consistent with the already mentioned hypothesis (Ungerleider and Mishkin, 1982) of a distinction between a dorsal stream (spatial system), running from the occipital to the parietal cortex, involved in the perception of spatial locations, and a ventral stream (visual system), running from occipital to the infero-temporal cortex, involved in the recognition of objects. The results obtained by Mellet and colleagues (1995; see also Mellet et al., 1996) revealed that the spatial system is engaged in both mental scanning of visual images and mental scanning of mental images.

#### 2.08.4.3 Imagery Value

In the study of the indexes of verbal materials best predicting memory performance, imagery value has usually resulted as the best predictor (Paivio, 1971), whereas the effects of item frequency/familiarity and associative value/meaningfulness resulted in weaker results and were partly explained by imagery value. This result was interpreted by Paivio (1971) as proof of the dual-code theory; in fact, a high-imagery-value item (e.g., the word 'train') evokes both a verbal and an imaginal encoding, and the double encoding enhances enhance the probability to get back the item. On the contrary a low-imagery-value item (e.g., the word 'range') only evokes a verbal encoding and thus has a poorer trace and a reduced probability to be recovered. Paivio (1971) also assumed that pictorial material has, by definition, a high imagery value and thus, if verbalizable, has the highest probability of having a double encoding; in other words, the picture superiority effect (better recall of the verbal label of a presented picture than of the corresponding presented word) should be caused by the same reasons that explain the superior recall of high-imagery words with respect to the recall of low-imagery words. However, this conclusion raises a series of perplexities (for a review, see Cornoldi and Paivio, 1982; Marschark and Cornoldi, 1990) because high-imagery verbal material differs from low-imagery verbal material in many respects only partly related to the use of mental imagery.

Different paradigms have been used to analyze the specific effects of mental imagery on the recall of high-imagery-value materials. For example, in a dual-task paradigm, participants are presented with a main task, which in this case can involve the retention of the high-imagery-value material. Simultaneously, they are also required to perform a secondary task, most of the time tapping one of the working memory components. (Some studies that have employed the dual-task paradigm have been presented in the preceding paragraphs, e.g., Salway and Logie, 1995; Bruyer and Scailquin, 1998). In a series of studies (e.g., Colpo et al., 1977), we simultaneously presented words, either with high or low imagery value, and pictures, and we found that the memory for high-imagery-value words was selectively impaired, suggesting that high-imagery words and pictures relied on the same type of resources.

A different paradigm concerns the manipulation of instructions. In general, specific instructions encouraging the use of mental imagery enhance memory with respect to instructions encouraging the use of a non-imagery strategy (e.g., repetition); furthermore, this effect seems to interact with the imagery value of the material, although the latter effect is not always clear (for a review, see Richardson, 1999).

### 2.08.4.4 Individual Differences in Imagery Abilities

The study of mental imagery has often used an individual differences approach, as already anticipated in the section concerning neuropsychological evidence. Also, within normal populations (i.e., in the absence of severe deficits), imagery ability differences can be observed. Actually, some of the tasks used for measuring spatial abilities require the maintenance and the manipulation of mental images, as in the case of tasks requiring mental rotation or the mental transformation of parts (mental folding, mental assembly, etc.). The traditional preference for imagery transformation tasks over other spatial tasks in the psychometric assessment of spatial abilities seems to result from the fact that the imagery transformation tasks involve a high degree of control and are thus central and related to the central structures of intelligence; however, at the same time, they maintain specific spatial features and are not only theoretically but also empirically distinguishable from other high-control tasks tapping verbal functions (Cornoldi and Vecchi, 2003).

Individual differences found with the use of objective measures are related to independent measures obtained with neurological (e.g., Charlot et al., 1992) and cognitive procedures. An example of this relationship is represented by the ability of solving ambiguous figures (Cornoldi et al., 1996). For example, Mast and Kosslyn (2002) found that the ability of rotating images was highly associated with reports of image reversals subsequent to an 180-degree rotation of a figure, whereas other imagery ability measures were not.

In the mental imagery field, the repertoire of differential measures has been enriched by many other measures, including subjective ones. Despite their methodological limitations, the self-report measures have been largely used and have produced a series of different tools. For example, the VVIQ test (Marks, 1973) requires that a person imagines, with either open or closed eyes, a scenario (e.g., a sunset) and reports how vivid his/her image is. The imagery ability is directly inferred by the sum of the values given to the different activated images. There have been concerns regarding the value of this subjective measure, voiced from different sides, but there is evidence that in some cases it may be a useful method (for a review, see McKelvie, 1995). For example, a VVIQ score may be predictive of the performance in a task requiring the memorization of visual objects. However, there is evidence that in some cases other types of subjective reports may have better predictive power. In particular, Graham and Morris (2003) suggested that a lack of a relationship between subjective measures and performance could be because they tap different components of mental imagery. To investigate this, the researchers administered two spatial tasks and two different self-report questionnaires to a group of subjects. One self-report, the VVIQ, mainly involved subjective visual experiences derived from long-term memory, whereas the other included items of the same kind used in the spatial tasks. They found that only the latter items predicted spatial performance, whereas there was no relationship between VVIQ and objective measures.

## 2.08.5 Educational and Other Applied Implications

The role of mental imagery in human cognition, for example, in reasoning, comprehension, and creativity, has been illustrated in several studies (Paivio, 1971; Richardson, 1999). This evidence suggests that training to effectively use visualization processes could enhance cognitive performance in many areas.

A well-known example of how mental imagery can be used in an educational context is represented by imagery mnemonics. This point was already emphasized by ancient Greeks and Romans, who stressed the importance of using mnemonics to improve learning. However, in the history of culture and education, the attitude toward mnemonics alternated between moments of enthusiasm, resulting from the enhancement of memory, and criticisms, resulting from the artificial connection between memory content and memory cues. For example, Cicero and Giordano Bruno were in favor of mnemonics, but Erasmus and Montaigne were not (Yates, 1966). Despite these different views, there is general agreement that mnemonics enhance memory and that they rely largely on the use of mental imagery (for a review, see Higbee, 1988). One key principle of imagery mnemonics is the creation of interactive images, which facilitates the retrieval of an element when the element imagined in interaction is available.

Mnemonics can be distinguished into two categories according to whether they rely on a specific rule or they require the prior creation of a cues file, and both categories of mnemonics very often rely on the use of mental imagery. Mnemonics based on a rule are of many different types. In the chaining mnemonics, people form a series of interactive images by combining in pairs the sequence of items. For example, given the sequence 'radio, cat, window, salad, etc.,' one could form the interactive image of a radio turned on by a cat, then a subsequent image of a cat jumping onto the windowsill, a window placed above a bowl of salad, and so on.

Another rule-based mnemonic that has received a lot of educational uses is represented by the keyword technique, mainly used for the study of foreign languages. The technique requires people to give a concrete imaginable meaning to the foreign word by associating it with a word in their own language with a similar sound. They then form an interactive image including the images of the new word and the word corresponding to the real meaning of the foreign word. The example given in **Figure 14** shows how a person could remember the Russian word 'likor' for 'battleship'. His first task would be to find an imaginable word similar in sound to the Russian word 'likor,' for example, Lincoln or liquor. The second task would be to create an interactive image including, for example, Lincoln and a battleship. As the two elements are very different in size, the person could use a zooming process to give a name to the small individual represented on the deck of the battleship.

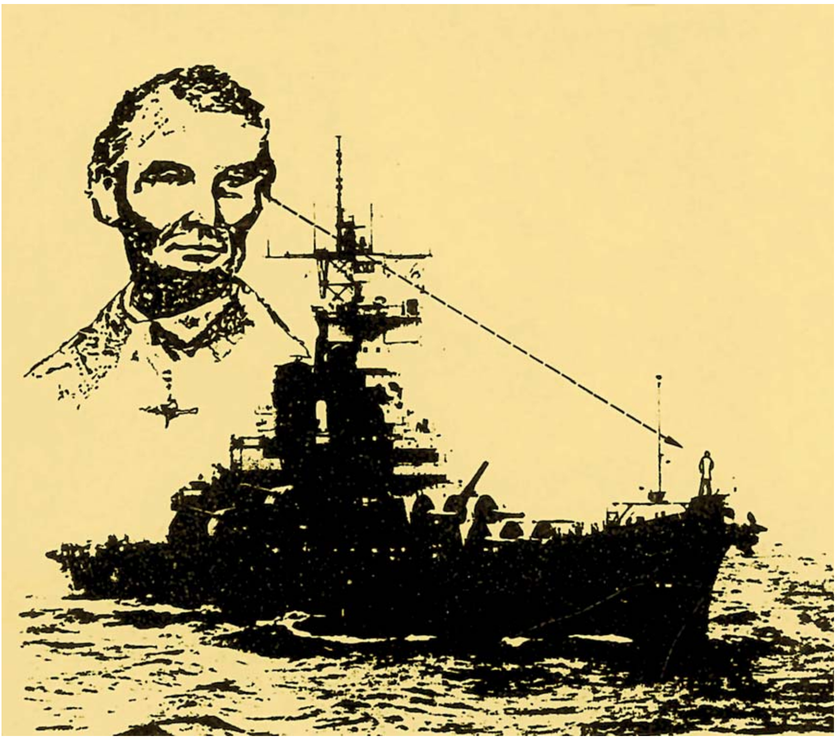

**Figure 14** Example of the use of the key-word technique to learn a foreign word ('likor' for 'battleship').

Despite the fact that imagery mnemonics can be considered artificial and distinguished from mnemonics based on semantic associations, in many cases the two components can act together. The example given in Figure 15 represents this possible synergy. In fact, a child trying to memorize the patterns illustrated in the matrix could simply rely on the semantic associations between items (e.g., a dish and a bowl can stay together), or the more effective rule of categorical clustering (a hen, a duck, a chicken, and a rabbit are all animals). However, the child could also take advantage of the memory of the visual form of the represented objects and the possibility of imagining them in interaction (a farm scenario with the animals, a bowl above a dish, etc.).

Mnemonics based on a cues file requires people to have already created a file containing a series of organized images that will be imagined in interaction with the new to-be-remembered material. At retrieval, the well-known cues file will be used for retrieving the new information memorized in interaction. Expert memorizers have always given preference to this category of mnemonics because it offers the possibility of storing huge amounts of material. There are reports of experts who created files of thousand of cues, either organized around spatial layouts or (more often) organized sequentially in correspondence with the number sequence. The most well known mnemonic based on a cues file is represented by the loci mnemonics, where people use landmarks arranged along a well-known pathway as cues. The example given in Figure 16 is adapted from the illustration given by Lindsay and Norman (1977) in their psychology handbook, where the pathway was in fact the route followed by Donald Norman to reach the Department of Psychology of the University of California at San Diego, starting from his home. The first landmarks selected by Norman were in sequence: (a) his own home, (b) the bay, (c) the train railway, and so on. Having to memorize a sequence of words, Norman could associate them with the sequence of landmarks (e.g., a radio left close to the gate of his home, a cat looking at a boat in the bay, a broken window on a train). If required to remember the sequence of words in perfect order, people using the loci mnemonics have no

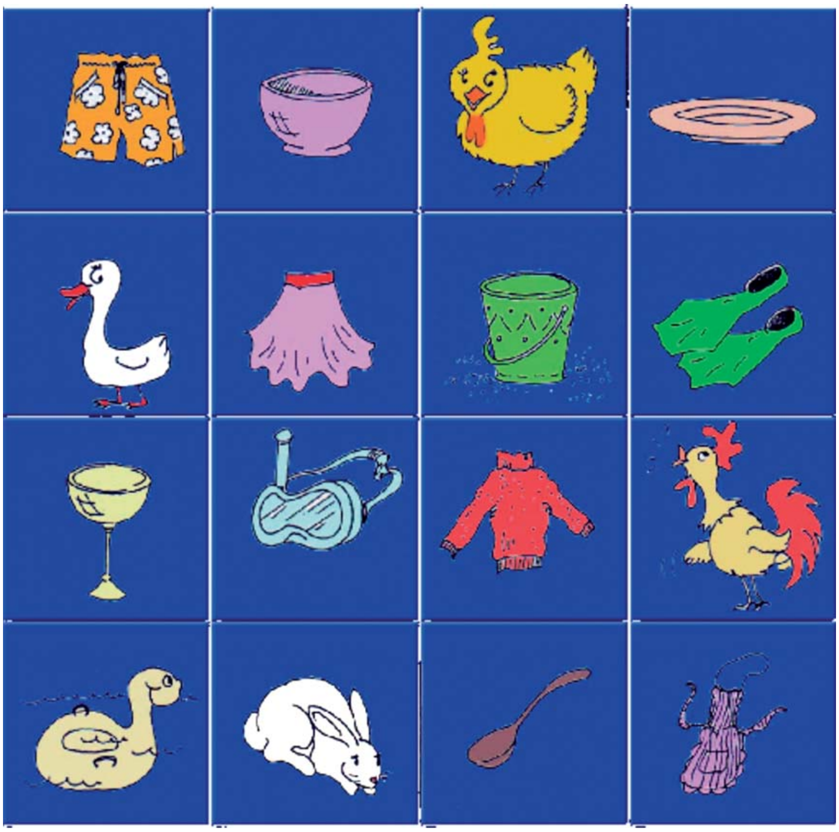

**Figure 15** Example of memory material that can take advantage of both semantic and mental imagery strategies.

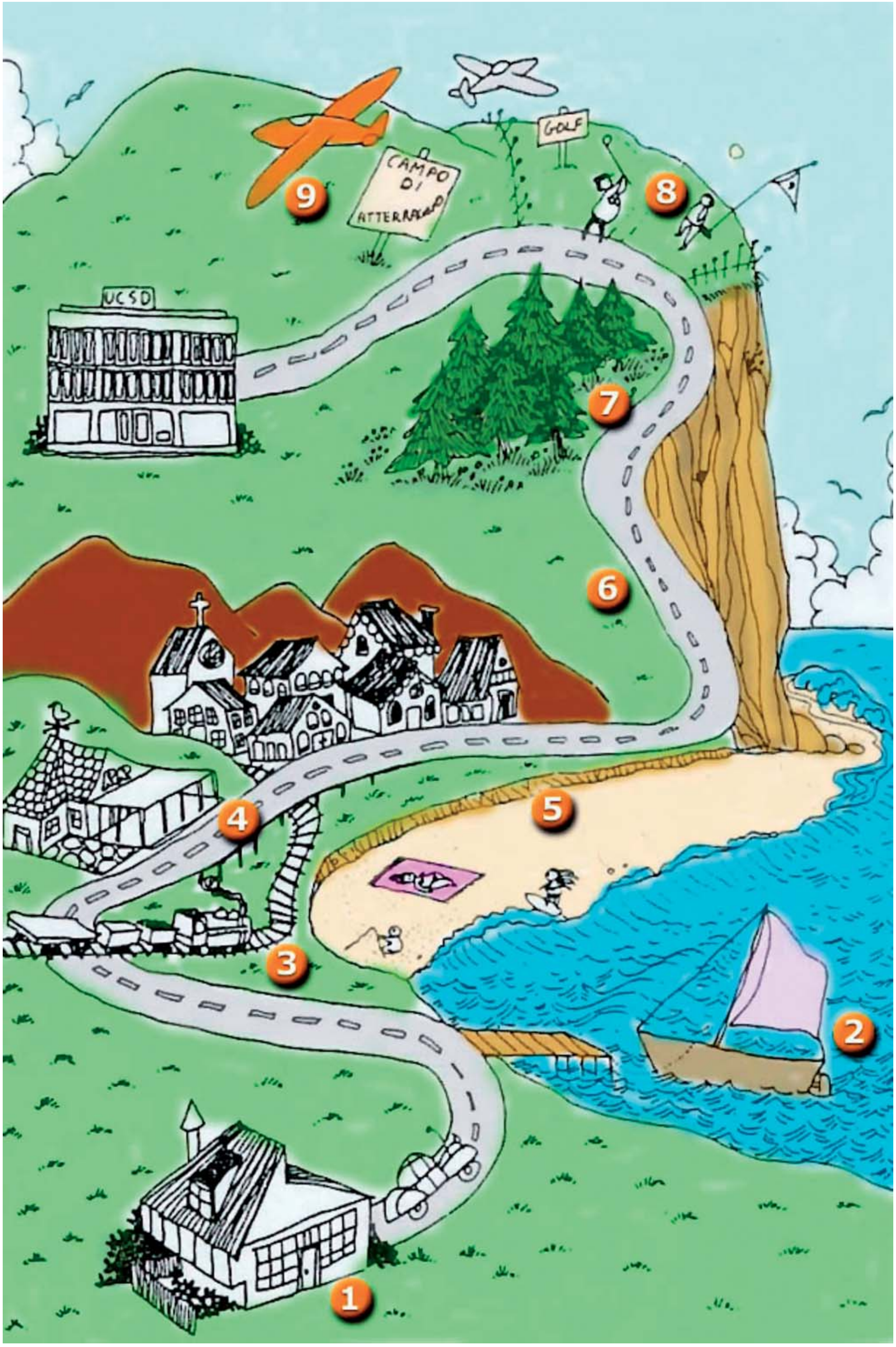


**Figure 16** An example of figure employed for using the loci mnemonic. Adapted from Lindsay PH and Norman DA (1977) *Human information processing,* 2nd edn. New York: Academic Press.

problems in retrieving their well-known route with its landmarks and thus retrieve the elements imagined in interaction with their landmarks.

A critique advanced against the loci and other imagery mnemonics is that they can be successfully used for memorizing isolated arbitrary series of items but do not offer an advantage in memorizing meaningful texts. However, there is evidence that loci mnemonics can also enhance memory for texts, although its advantage is more evident when a text is orally presented than when it is written, because of the competition of visual processes involved in imagining and reading (Cornoldi and De Beni, 1991).

## 2.08.6 Concluding Comments

Mental imagery represents a very relevant part of mental life. Because of its pervasiveness, internal status, and complexity, its study raises a series of methodological problems and requires differentiations and specifications. In this chapter we described mental imagery with reference to different approaches and theories. In particular, we illustrated the debate between prepositional and imagery theorists and the efforts devoted to distinguishing between different imagery processes and representations. The classical problem concerning the extent of the analogy between visual perception and visual mental imagery may find a response in the consideration of the differences from images directly derived from experience and images generated from long-term memory information. Furthermore, the consequences resulting from the use of different types of long-term memory information can be examined within the approach distinguishing between general, specific, and other types of mental images. However, many issues in the field, for example, the dynamic nature of mental images, their role in different life activities (like creative processes, thinking, meditation, and so on), and the study of individual differences, appear still in need of further research developments.

## References


Baddeley AD (1986) *Working Memory*. Oxford: Oxford University Press.

Baddeley AD and Andrade J (2000) Working memory and the vividness of imagery. *J. Exp. Psychol. Gen.* 129: 126–145.

Baddeley AD and Hitch GJ (1974) Working memory. In: Bower GA (ed.) *Recent Advances in Learning and Motivation*, pp. 47–90. New York: Academic Press.

Beschin N, Cocchini G, Della Sala S, and Logie RH (1997) What the eyes perceive, the brain ignores: A case of pure unilateral representational neglect. *Cortex* 33: 3–26.

Bisiach E and Luzzatti C (1978) Unilateral neglect of representational space. *Cortex* 14: 129–133.

Brandimonte MA and Gerbino W (1993) Mental image reversal and verbal recoding: When ducks become rabbits. *Mem. Cognit.* 21: 23–33.

Brandimonte MA, Hitch GJ, and Bishop DV (1992a) Influence of short-term memory codes on visual image processing: Evidence from image transformation tasks. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 157–165.

Brandimonte MA, Hitch GJ, and Bishop DV (1992b) Manipulation of visual mental images in children and adults. *J. Exp. Child Psychol.* 53: 300–312.

Brewer MB (1988) A dual process model of impression formation. In: Srull TK and Wyer RS Jr. (eds.) *Advances in Social Cognition. Vol. I*, pp. 1–36. Hillsdale, NJ: Erlbaum.

Brooks LR (1968) Spatial and verbal components of recall. *Can. J. Psychol.* 22: 349–368.

Bruyer R and Scailquin JC (1998) The visuospatial sketchpad for mental images: Testing the multicomponent model of working memory. *Acta Psychol,* 98: 17–36.

Cabeza R and Nyberg L (2000) Imaging cognition II: An empirical review of 275 PET and fMRI studies. *J. Cogn. Neurosci.* 12: 1–47.

Carroll JB (1993) *Human Cognitive Abilities: A Survey of Factor-Analytic Studies*. New York: Cambridge University Press.

Charlot V, Tzourio N, Zilbovicius M, Mazoyer B, and Denis N (1992) Different mental-imagery abilities result in different regional cerebral blood-flow activation patterns during cognitive tasks. *Neuropsychologia* 30: 565–580.

Colpo C, Cornoldi C, and De Beni R (1977) Competition in memory between high and low imagery value stimuli and visual stimuli: Temporal conditions for occurrence of interference effects. *Ital. J. Psychol.* 4: 387–402.

Cornoldi C, Cavedon A, De Beni R, and Pra-Baldi A (1988) The influence of the nature of material and of mental operations on the occurrence of the bizarreness effect. *Q. J. Exp. Psychol. Hum. Exp. Psychol.* 40: 73–85.

Cornoldi C, Cortesi A, and Preti D (1991) Individual differences in the capacity limitations of visuospatial short-term memory: Research on sighted and totally congenitally blind people, *Mem. Cognit.* 19: 459–468.

Cornoldi C and De Beni R (1991) Memory for discourse: Loci mnemonics and the oral presentation effect. *Appl. Cogn. Psychol.* 5: 511–518.

Cornoldi C, De Beni R, Cavedon A, Mazzoni G, Giusberti F, and Marucci F (1992) How can a vivid image be described? Characteristics influencing vividness judgement and the relationship between vividness and memory. *J. Ment. Imag.* 16: 89–108.

Cornoldi C, De Beni R, and Giusberti F (1996a) Meta-imagery: Conceptualization of mental imagery and its relationship with cognitive behavior. *Psychologische Beitrage* 38: 484–499.

Cornoldi C, De Beni R, Giusberti F, and Massironi M (1998) Memory and imagery: A visual trace is not a mental image. In: Conway MA, Gathercole SE, and Cornoldi C (eds.) *Theories of Memory, Vol. II*, pp. 87–110. Hove: Psychology Press.

Cornoldi C, De Beni R, and Pra Baldi A (1989) Generation and retrieval of general, specific and autobiographic images representing concrete nouns. *Acta Psychol.* 72: 25–39.

Cornoldi C and Guglielmo A (2001) Children who cannot imagine. *Korean J. Thinking Problem Solving* 11: 99–112.

Cornoldi C, Logie R, Brandimonte MA, Kauffman G, and Reisberg D (1996b) *Stretching the Imagination*. New York: Oxford University Press.

Cornoldi C and Paivio A (1982) Imagery value and its effects on verbal memory: A review. *Arch. Psicol. Neurol. Psich.* 43: 171–192.
Cornoldi C, Rigoni F, Tressoldi PE, and Vio C (1999) Imagery deficits in nonverbal learning disabilities. *J. Learn. Disabil.* 32: 48–57.
Cornoldi C and Vecchi T (2000) Mental imagery in blind people: The role of passive and active visuospatial processes. In: Morton AH (ed.) *Touch, Representation and Blindness*, pp. 29–58. Oxford: Oxford University Press.
Cornoldi C and Vecchi T (2003) *Visuospatial Working Memory and Individual Differences*. Hove: Psychology Press.
D'Esposito M, Detre JA, Aguirre GK, et al. (1997) A functional MRI study of mental image generation. *Neuropsychologia* 35: 725–730.
Denis M and Kosslyn SM (1999) Scanning visual mental images: A window on the mind. *Curr. Psychol. Cogn.* 18: 409–465.
De Beni R and Cornoldi C (1988) Imagery limitations in totally congenitally blind subjects. *J. Exp. Psychol. Learn. Mem. Cogn.* 14: 650–655.
De Beni R and Pazzaglia F (1995) Memory for different kinds of mental images: Role of contextual and autobiographic variables. *Neuropsychologia* 11: 1359–1371.
Della Sala S, Gray C, Baddeley A, Allamano N, and Wilson L (1999) Pattern span: A tool for unwelding visuo-spatial memory. *Neuropsychologia* 37: 1189–1199.
Einstein G O, McDaniel M A, and Lackey S (1989) Bizarre imagery, interference, and distinctiveness. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 137–46.
Farah MJ, Hammond KM, Levine DN, and Calvanio R (1988) Visual and spatial mental imagery: Dissociable systems of representation. *Cognit. Psychol.* 20: 439–462.
Finke RA, Pinker S, and Farah MJ (1989) Reinterpreting visual patterns in mental imagery. *Cogn. Sci.* 13: 51–78.
Galton F (1883) *Inquiries into Human Faculty*. London: Macmillan.
Gardini S, De Beni. R., Cornoldi C, Bromiley A, and Venneri A (2005) Different neuronal pathways support the generation of general and specific mental images. *Neuroimage* 27: 544–552.
Goldenberg G (1989) The ability of patients with brain damage to generate mental visual images. *Brain* 112: 305–325.
Goldenberg G (1992) Loss of visual imagery and loss of visual knowledge – A case study. *Neuropsychologia* 30: 1081–1099.
Graham DM and Morris PE (2003) The relationship between self-reports of imagery and spatial ability. *Br. J. Psychol.* 94: 245–273.
Helstrup T, Cornoldi C, and De Beni R (1997) Mental images: Specific or general, personal or impersonal? *Scand. J. Psychol.* 38: 189–197.
Higbee KL (1988) *Your Memory. How It Works and How to Improve It*, 2nd edn. New York: Prentice Hall.
Holt RR (1964) Imagery: The return of the ostracized. *Am. Psychol.* 19: 254–264.
Intons-Peterson MJ and McDaniel MA (1991) Symmetries and asymmetries between imagery and perception. In: Cornoldi C and McDaniel MA (eds.) *Imagery and Cognition*. New York: Springer-Verlag.
Kessels RPC, De Haan EHF, Kappelle LJ, and Postma A (2002a) Selective impairments in spatial memory after ischaemic stroke. *J. Clin. Exp. Neuropsychol.* 24: 115–129.
Kessels RPC, Kappelle LJ, De Haan EHF, and Postma A (2002b) Lateralization of spatial memory processes: Evidence on spatial span, maze learning, and memory for object locations. *Neuropsychologia* 40: 1465–1473.
Kosslyn SM (1980) *Image and Mind*. Cambridge, MA: Harvard University Press.
Kosslyn SM (1987) Seeing and imagining in the cerebral hemispheres: A computational approach. *Psychol. Rev.* 94: 148–175.
Kosslyn SM (1994) *Image and Brain*. Cambridge, MA: MIT Press.
Kosslyn SM, Ball TM, and Reiser BJ (1978) Visual images preserve metric spatial information: Evidence from studies of image scanning. *J. Exp. Psychol. Hum. Percept. Perform.* 4: 47–60.
Kosslyn SM, Alpert NM, Thompson WL, et al. (1993) Visual mental imagery activates topographically organized visual cortex: PET investigations. *J. Cogn. Neurosci.* 5: 263–287.
Kosslyn SM, Ganis G, and Thompson WM (2001) Neural foundations of imagery. *Nat. Rev. Neurosci.* 2: 635–642.
Kosslyn SM, Koenig O, Barrett A, Cave CB, Tang J, and Gabrieli JDE (1989) Evidence for two types of spatial representations: Hemispheric specialization for categorical and coordinate relations. *J. Exp. Psychol. Hum. Percept. Perform.* 15: 723–735.
Kosslyn SM, Maljkovic V, Hamilton S, Horowitz G, and Thompson W (1995) Two types of image generation: Evidence for left and right hemisphere processes. *Neuropsychologia* 33: 1485–1510.
Kosslyn SM, Pascual-Leone A, Felician O, et al. (1999) The role of area 17 in visual imagery: Convergent evidence from PET and rTMS. *Science* 284: 167–170.
Kosslyn SM, Thompson WL, and Alpert NM (1997) Neural systems shared by visual imagery and visual perception: A positron emission tomography study. *Neuroimage* 6: 320–334.
Kosslyn SM and Thompson WL (2003) When is early visual cortex activated during visual mental imagery? *Psychol. Bull.* 129: 723–746.
Lanfranchi S, Cornoldi C, and Vianello R (2004) Verbal and visuospatial working memory deficits in children with Down syndrome. *Am. J. Ment. Retard.* 6: 456–466.
Lansdale MW (1998) Modeling memory for absolute location. *Psychol. Rev.* 105: 351–78.
Lindsay PH and Norman DA (1977) *Human Information Processing*, 2nd edn. New York: Academic Press.
Logie RH (1995) *Visuo-Spatial Working Memory*. Hove: Erlbaum.
Mammarella IC and Cornoldi C (2005) Sequence and space. The critical role of backward spatial span in the working memory deficit of visuospatial learning disabled children. *Cogn. Neuropsychol.* 22: 1055–1068.
Marschark M and Cornoldi C (1990) Imagery and verbal memory. In: Cornoldi C and Mc Daniel M (eds.) *Imagery and Cognition*, pp. 133–182. New York: Springer-Verlag.
Marks D (1973) Visual imagery differences in the recall of pictures. *Br. J. Psychol.* 64: 17–24.
Mast FW and Kosslyn SM (2002) Visual mental images can be ambiguous: Insights from individual differences in spatial transformation abilities. *Cognition* 86: 57–70.
McKelvie S (1995) The VVIQ as a psychometric test of individual differences in visual imagery vividness: A critical quantitative review and plea for direction. *J. Ment. Imag.* 19: 1–106.
Mellet E, Tzourio N, Denis M, and Mazoyer B (1995) A positron emission tomography study of visual and mental spatial exploration. *J. Cogn. Neurosci.* 7: 433–445.
Mellet E, Tzourio N, Crivello F, Joliot M, Denis M, and Mazoyer B (1996) Functional anatomy of spatial mental imagery generated from verbal instructions. *J. Neurosci.* 16: 6504–6512.
Paivio A (1971) *Imagery and Verbal Processes*. New York: Holt: Rinehart and Winston.
Paivio A (1978) Mental comparisons involving abstract attributes. *Mem. Cognit.* 6: 199–208.

Paivio A, Yuille JC, and Madigan SA (1968) Concreteness imagery, and meaningfulness values for 925 nouns. *J. Exp. Psychol.* 76: 1–25.

Pazzaglia F and Cornoldi C (1999) The role of distinct components of visuo-spatial working memory in the processing of texts. *Memory* 7: 19–41.

Pearson D, De Beni R, and Cornoldi C (2001) The generation, maintenance, and transformation of visuo-spatial mental images. In: Denis M, Logie RH, Cornoldi C, De Vega M, and Engelkamp J (eds.). *Imagery, Language and Visuo-Spatial Thinking*, pp. 1–27. Hove: Psychology Press.

Pickering SJ, Gathercole SE, Hall M, and Lloyd SA (2001) Development of memory for pattern and path: Further evidence for the fractionation of visual and spatial short-term memory. *Q. J. Exp. Psychol.* 54A: 397–420.

Postma A and De Haan EHF (1996) What was there? Memory for object locations. *Q. J. Exp. Psychol.* 49A: 178–199.

Pylyshyn ZW (1973) What the mind's eye tells the mind's brain: A critique of mental imagery. *Psychol. Bull.* 80: 1–24.

Pylyshyn Z (1981) The imagery debate: Analogue media versus tacit knowledge. *Psychol. Rev.* 88: 16–45.

Pylyshyn Z (2002) Mental imagery: In search of a theory. *Behav. Brain Sci.* 25: 157–182.

Richardson A (1969) *Mental Imagery*. New York: Springer.

Richardson JTE (1980) *Mental Imagery and Human Memory*. London: McMillan.

Richardson JTE (1999) *Cognitive Psychology: A Modular Course*. Hove: Psychology Press.

Richardson JTE and Vecchi T (2002) A jigsaw-puzzle imagery task for assessing active visuospatial processes in old and young people. *Behav. Res. Methods Instrum. Comput.* 34: 69–82.

Roland PE and Gulyas B (1994) Visual imagery and visual representation. *Trends Neurosci.* 17: 281–287.

Roland PE and Friberg L (1985) Localization of cortical areas activated by thinking. *J. Neurophysiol.* 53: 1219–1243.

Salway AFS and Logie RH (1995) Visuospatial working memory, movement control and executive demands. *Br. J. Psychol.* 86: 253–269.

Shepard RN and Metzler J (1971) Mental rotation of three dimensional objects. *Science* 171: 701–703.

Slotnick SD, Thompson WL, and Kosslyn SM (2005) Visual mental imagery induces retinotopically organized activation of early visual areas. *Cereb. Cortex* 15: 1570–1583.

Snodgrass JG and Vanderwart M (1980) A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *J. Exp. Psychol. Hum. Learn. Mem.* 6: 174–215.

Thompson WL and Kosslyn SM (2000) Neural systems activated during visual mental imagery: A review and meta-analyses. In: Toga AW and Mazziotta JC (eds.) *Brain Mapping: The Systems*, pp. 535–560. San Diego: Academic Press.

Trojano L and Grossi D (1994) A critical review of mental imagery defects. *Brain Cogn.* 24: 213–243.

Ungerleider LG and Mishkin M (1982) Two cortical visual systems. In: Ingle DJ, Goodale MS, and Mansfield RJW (eds.) *The Analysis of Visual Behaviour*, pp. 549–586. Cambridge, MA: MIT Press.

Vecchi T and Cornoldi C (1999) Passive storage and active manipulation in visuo-spatial working memory: Further evidence from the study of age differences. *Eur. J. Cogn. Psychol.* 11: 391–406.

Vecchi T and Richardson JTE (2000) Active processing in visuo-spatial working memory. *Cahiers Psych. Cogn.* 19: 3–32.

Yates FA (1966) *The Art of Memory*. London: Routledge and Kegan Paul.

# 2.09 Distinctiveness and Memory: A Theoretical and Empirical Review

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## 2.09.1 Introduction

My memories appear as a varied landscape, with fields and trees and distant mountains. I can distinguish each blade of grass at my feet, I see the individual veins on the leaves on a nearby tree and the brown corrugated grain of the tree's bark. Farther away, the blades of grass are lost in a field of green, and the trees on the hillside are marbled clumps of color. However, I can clearly see a lone tree in the middle of a distant field. On the horizon I can see the blue haze of the mountains, occasionally interrupted with an outcrop of white rock. I know the mountains must be covered with trees, but I cannot separate one from another. The clarity of my memories, like the clarity of my perceptions, appears to be determined by both distance and contrast. In this manner, contrast, or distinctiveness, is a fundamental concept in any theoretical treatment of memory.

Theory and research concerning distinctiveness and memory have long and fascinating histories that have been recounted in detail elsewhere (see Wallace, 1965; Schmidt, 1991; Hunt, 1995). These histories unfailingly begin with Hedwig von Restorff, a post-doctoral assistant in Wolfgang Köhlers's laboratory. von Restorff was one of the first to argue that the Gestalt perceptual principles applied to memory traces (Geissler, 2001). Principles of organization and the perception of figure and ground lend themselves nicely to the clarity of memory for that metaphorical lone tree in the field. von Restorff (1933) argued that "the rules according to which the reproducibility of items is a function of the structure of the list are consistent with the laws governing whether individual parts in the field of vision remain independent or integrated into a perceptible whole." (Von Restorff, 1933: p. 323) The perception of a single "figure in a whole" (or tree in a forest) is impaired because it becomes a part of the whole. The perception of a tree in a field does not suffer from such interference (Von Restorff, 1933: p. 327). Studies of the von Restorff effect and distinctiveness effects in general can be seen as attempts to understand the good memory for the metaphorical lone tree.

In the following pages, I provide a summary of theoretical and empirical treatments of the concept of distinctiveness in memory research. I begin with a few of my own organizational principles, followed by three theoretical perspectives on distinctiveness in memory. Then I provide a rather long catalog of empirical phenomena that roughly fit under the distinctiveness umbrella. I conclude with a cautionary note concerning the usefulness of distinctiveness as a theoretical construct.

## 2.09.2 Organizing Principles

Imagine that I am looking at a giant oak tree at the height of fall colors. My visual field is completely filled with the image of the tree, and every leaf on the tree, save one, has turned bright red. The green leaf stands out in this perceptual field. There is nothing unusual about a green leaf; it gains its distinctive character by virtue of its context. In contrast, I do not recall ever seeing a purple polka-dot leaf on a tree. Perhaps a purple polka-dot leaf on a tree would be distinctive in any context. Note that individual leaves on a tree full of purple polka-dot leaves would not stand out from one another. However, the tree as a whole would stand out in a typically green forest. Thus, when one tries to define the distinctiveness of an experience, one must consider the domain, or to push the metaphor, the field of view.

Toward this end, researchers often distinguish between context-dependent, or primary, distinctiveness and absolute or secondary distinctiveness (Schmidt, 1991). Primary distinctiveness (from W. James's primary memory) is defined relative to the immediate context or, for example, a list of words in a memory experiment. For example, a tall tree in the middle of a field of grass stands out in its immediate context, and a single word printed in red stands out in the context of a list of words all printed in black. Secondary distinctiveness is defined with regard to the previous history of the observer and to experiences stored in long-term or James's secondary memory. Examples of secondary distinctiveness might include seeing a purple polka-dot tree or reading the sentence: The banker floated across the puddle on a newspaper.

This discussion of primary and secondary distinctiveness naturally leads to a discussion of experimental design or, more specifically, list structure. The study of primary distinctiveness requires a within-subjects or mixed-list design. That is, the participants must experience material that stands out within the experimental context. In contrast, secondary distinctiveness can be studied in both mixed-list and between-subjects design. For example, suppose one were interested in the effect of word frequency on memory. In a between-subjects design, one group of participants could view a list of frequent words, while a second group would view a list of infrequent (i.e., distinctive) words. In a within-subjects design, participants would view a mixed list of frequent and infrequent words. Interestingly, the word frequency effect in recall may only appear in mixed-list designs (DeLosh and McDaniel, 1996).

Researchers have also wrestled with the problem of the locus of the effect of distinctiveness in memory research. von Restorff addressed this issue when she stated, "Either similar forces are at work in the 'trace field' as are in perception, *or* [her emphasis] our results are merely the direct results of Gestalt effects in perception" (von Restorff, 1933: p. 323). In modern terms, we might ask whether the effects of distinctiveness result from processing differences during encoding or differences in the stored representations or arise during the retrieval stage. von Restorff concluded that the effects operate on the memory traces, combining representational and retrieval views of distinctiveness. Other researchers have concluded that all three stages contribute to the effects of distinctiveness (see Schmidt, 1991, and Hunt, 1995).

McDaniel and Geraci (2006) argued that the effects of primary distinctiveness typically occurred at the retrieval stage, whereas secondary distinctiveness effects resulted from both encoding and retrieval processes. With manipulations of primary distinctiveness, memory for the nondistinctive surrounding items on a list is not impaired, particularly on measures of recognition memory (Schmidt, 1985). This suggests that the processing of the distinctive item does not distract from the processing of the common items on the list. In addition, the position of the distinctive item within the list does not seem to impact the effect of primary distinctiveness. That is, the distinctive item is well recalled even when it is the first item in the list (Hunt, 1995). In this list position, the distinctiveness advantage must have resulted from the item standing out in memory rather then during its initial presentation. In contrast, with secondary distinctiveness (e.g., bizarre sentences), the presence of the distinctive items appears to impair memory for the common items, and list position is an important factor. For example, McDaniel and Geraci (2006) found that bizarre and common sentences were recalled equally well if the bizarre sentence appeared in the first half of a list. The typical bizarreness advantage was found when the bizarre sentences appeared in the second half of the list. These results demonstrate the importance of encoding processes in supporting the effects of secondary distinctiveness. Retrieval processes also play an important role. For example, the relatively good memory for bizarre sentences is often found in free recall but not cued recall (Einstein and McDaniel, 1987) or serial-order recall (McDaniel et al., 2000).

Despite McDaniel and Geraci hypothesis, few would argue that encoding and perceptual processes are not important in primary distinctiveness. After all, the green leaf on a red tree will not stand out if one is colorblind. That is to say, the features that support trace distinctiveness must be encoded. For example, consider the experiment reported by Van Overschelde et al. (2005). Research participants viewed names of American football teams (e.g., Texas Longhorns). In one condition, this list contained only the names of college teams, and in a second condition, the list contained one college team isolated in a group of professional teams. Only participants with a high knowledge of football, who were thus able to discriminate between professional and college teams, showed a memory advantage for the isolated name. Hunt and Lamb (2001) asked participants to name either a similarity or a difference between adjacent words in a list. In the control list, all the words belonged to the same conceptual category (e.g., tools). In the isolation list, one word was from a different conceptual category (e.g., vegetables) than the other words on the list. The typical isolation effect was found following the same judgments, but not following the difference judgments. Clearly, prior knowledge and encoding strategies play an important role in producing the effects of primary distinctiveness.

## 2.09.3 Theoretical Perspectives

From the discussion in the preceding section, we can see that the domain, the type of experimental design, and the locus of the effect are all central to studies concerning the impact of distinctiveness on memory. In addition, researchers have offered numerous definitions of distinctiveness (see Schmidt, 1991, and Hunt, 2006, for reviews). These include the ideas that distinctiveness is a property of an item, an item in context, a property of a memory trace, a property of a retrieval cue, a property of a cue in a context, a type of processing, and the response of an individual to a stimulus. Definitions of distinctiveness are typically tied to theoretical perspectives, and numerous theories have been proposed. The theories can be grouped into three primary classes: organizational theories, representational theories, and those theories focusing on the affective response of the perceiver. Each of these perspectives is outlined below.

### 2.09.3.1 Organizational Theories

Organizational theories can trace their roots to von Restorff, and thus to Gestalt approaches to psychology. Within this framework, a distinctive item is apart, or in a different category, than its physical or temporal neighbors. Thus, in a list-learning task, the distinctive item changes the organizational structure of the list. Bruce and Gains (1976) used this account to explain clustering of related isolated items in free recall. These results could not easily be explained by increased attention to or rehearsal of (Rundus, 1971) the distinctive items.

Reed Hunt and his associates have offered several elaborations on organizational approaches. These are variously referred to as the distinctiveness hypothesis (Hunt and Mitchell, 1978; Hunt and Elliot, 1980; Hunt and Einstein, 1981; Hunt and Mitchell, 1982), the organization and distinctiveness view (Hunt and McDaniel, 1993), and most recently and generally, as distinctive processing (Hunt, 2006). A common theme running through this research is the focus on individual item and relational processing in memory. For this reason, I refer to this approach as the individual item/relational processing view. Individual item (distinctive) processing serves to distinguish each item form other items in a set. Relational processing highlights features shared by items within a set, helping to delineate the search set. Depending on the nature of the set of items and the retrieval context, each kind of processing can be beneficial to memory performance. Within this framework, "distinctiveness is the processing of difference in the context of similarity" (Hunt, 2006: p. 22). So, for example, in a group of relatively homogeneous items individual item (distinctive) processing would serve to differentiate the items and greatly improve recall (see the discussion of the Hunt and Lamb, 2001 study in section 2.09.2). However, in a list of unrelated items, relational (organizational) processing would benefit recall more than individual item processing.

Organizational approaches have numerous strengths. These include their application to both recognition and recall performance and their explanation for the effects of distinctive items on organizational processes in free recall. In addition, the general framework is applicable to a wide range of phenomena, including the isolation effect, the bizarre imagery effect, the humor effect, the word frequency effect, and the concreteness effect. Each of these effects, and their relation to distinctiveness, is discussed in section 2.09.4. The drawback of this approach is that it treats distinctiveness as an explanation, or a theoretical construct, rather than as an independent variable (Hunt, 2006). As such, Hunt's ideas can be used to explain why a distinctive item is well remembered in a given situation. However, the approach does not specify a direct measure of the distinctiveness of an experience. That is to say, it cannot predict what conditions will produce mnemonic isolation.

### 2.09.3.2 Representational Theories

According to a representational approach, the distinctive item has a memory representation that shares few features with other items in memory. That is, distinctiveness is the converse of similarity as defined by researchers such as Tversky (1977) and Shepard (1987). Thus, unlike Hunt's individual item/relational approach, this approach starts with a specification of what makes an item distinctive, and the focus is less on the processing or organization of an experience and more on static/mathematical ratios. Representational approaches can be traced to Murdock (1960) and his conveyor belt model (Murdock, 1972, 1974). In Murdock's approach, each item is assigned a value along some dimension (e.g., time or size). The distinctiveness of an item is then defined as a function of the sum of the difference between that item and other items on a list. Relative distinctiveness of a set of items is then defined as the ratio of each item's distinctiveness value to the sum of the distinctiveness values of other items in the set. This model has been most successfully applied to the serial position curve (see Neath, 1993), where each item's temporal position was used to calculate item distinctiveness.

Eysenck (1979) also described a representational view of distinctiveness, wherein distinctiveness was defined in terms of sets of overlapping information. Within this framework, three sources of information contributed to recognition memory: information from previous encodings, information from the study-trial encoding, and information in the test trial encoding. "[T]he most important factor in recognition memory is the extent to which the test-trial encoding contains information that is unique to the study-trial encoding" (Eysenck, 1979: p. 111). Recognition performance should then be a ratio of this distinctive information to shared information.

Whereas the Eysenck (1979) and Neath (1993) treatments focused on recognition performance, Nairne et al. (1997; see also Nairne, 2006) extended the framework to recall. Nairne et al. combined uncertainty (perturbation) in serial position information with a metric of positional distinctiveness to predict primacy and recency as a function of presentation rate and retention interval. Nairne (2006) applied the framework to the isolation effect in free recall, providing what is perhaps the most comprehensive coverage of distinctiveness within the representational perspective. This model might be seen as a more formal development of Eysenck's (1979) ideas. Nairne argued that recall is a function of the extent to which a retrieval cue uniquely matches a recall target. Such matches were determined by item similarity, which was defined in terms of shared semantic features. Item distinctiveness was the ratio of the similarity of the cue to the target item to the sum of the similarity of the cue to other possible candidates for recall.

Representational models are often presented in formal mathematical descriptions, providing some precision to their predictions, a true advantage over the verbal descriptions offered by the organizational approach. However, as noted above, most of the formal treatments have been applied to the serial position curve. Applications to other phenomena that fall under the distinctiveness rubric are rare. Schmidt (1996) applied the Murdock (1960) and Neath (1993) frameworks to the typicality effect in free recall and found that they made inaccurate predictions. For example, Murdock's model incorrectly predicted that both very typical and atypical items embedded in a list of moderately typical items should be distinctive and thus well recalled or recognized. In addition, these theories fail to take into account recent developments concerning similarity (e.g., Gati and Tversky, 1984; Murphy and Medin, 1985; Medin et al., 1993). Items should not be thought of as containing a fixed set of features, with each feature having a fixed contribution to item similarity. Rather, feature selection and feature weights are determined by the context in which an item appears, and by the processing strategies brought to the task (see Hunt and McDaniel, 1993; Schmidt, 1996). Given the lack of a firm metric of similarity, it is difficult to construct a ratio of distinctive to shared features.

The representational approaches seem to have particular difficulty dealing with secondary distinctiveness. For example, within Murdock's (1960) theory, the distinctiveness of an item is calculated relative to other items in a list, not relative to the set of all items stored in memory. Yet, secondary distinctiveness is defined in terms of this larger set of information. How then, for example, could one calculate the relative distinctiveness of, say, high- and low-frequency words? Within Eysenck's framework, independent of experimental design, semantic processing leads to more distinctive memory traces than phonetic processing. As predicted, semantic processing leads to better memory than phonetic processing in both within- (Craik and Tulving, 1975) and between-subjects designs (see Johnston and Jenkins, 1971). Similarly, Valentine (1991) described a representational theory in his explanation of a good memory for distinctive faces. Within this view, faces are represented in multidimensional feature space. Typical faces fall in relatively crowded regions of this space containing many exemplars, whereas atypical faces fall in relatively empty regions. Item discrimination processes are thus relatively easy for atypical compared with typical faces. As a result, the discrimination advantage enjoyed by atypical faces should be present independent of experimental design. Thus, from a representational view, one can define distinctiveness in relative terms, in which case the theory cannot be applied to secondary distinctiveness. Or, one can define distinctiveness in absolute terms, in which case distinctiveness should aid memory independent of experimental design. Thus, representational views stumble over the fact that the effects of secondary distinctiveness are confined to within-subjects designs (see Section 2.09.4).

### 2.09.3.3 Affective Response Theories

One can imagine the landscape of everyday memories painted in neutral affective tones. However, some experiences would be painted in the vivid colors of strong emotional responses. These emotionally laden experiences should stand out in memory. The distinctive item, within this framework, is one that leads to a heightened physiological state of arousal or emotion. In Schmidt's (1991) classification, experiences that stood out because of their emotional content were classified as examples of emotional distinctiveness. For example, Hirshman et al. (1989) argued that the bizarreness effect resulted from the surprise experienced by participants at finding a bizarre sentence in a mixed list of bizarre and common sentences. Conversely, some researchers have argued that the effects of emotion on memory should be thought of as von Restorff effects (Loftus and Burns, 1982) or as attributable to distinctiveness (McCloskey et al., 1988; Dewhurst and Perry, 2000).

Numerous researchers have tied von Restorff, isolation, or distinctiveness effects to physiological correlates of increased attention, surprise, or emotion. Researchers within this tradition can probably trace their ideas to the work of Sokolov (1963), James (1890), and ultimately Darwin (1872). The nervous system ignores steady-state information and responds to change. From a Jamesian perspective, our perceptions of these nervous system responses 'are' the emotions we feel. These responses can be seen in indices of the orientation reflex (e.g., increased skin conductance, Gati and Ben-Shakhar, 1990), in the N400 and the P300 cortical responses (Fabiani et al., 2000), and in the release of stress-related hormones (Gold, 1992). Exactly how these responses translate into memory effects varies from theory to theory.

James (1890) argued that an emotional experience may be "accompanied by an extraordinary degree of attention" (James, 1872: p. 671). Similarly, Easterbrook (1959) argued that arousal may lead to a narrowing of attention. Bower (1992; see also Rundus, 1971) argued that an emotional event would disrupt rehearsal processes, leading to decreased rehearsal of surrounding material and increased rehearsal of the emotional item. Burke et al. (1992) suggested that an emotional experience would lead to a shift in the priority of information processing. Thus, one explanation within affective theories of distinctiveness is that outstanding events (Ellis et al., 1971) receive extra attention and processing, and that this extra processing may be at the expense of other stimuli.

Gold (1987, 1992) focused on the neurobiological processes supporting memory. He argued that information storage was influenced by neuroendocrine responses that may promote memory coding. Specifically, stress releases epinephrine, which in turn leads to increased levels of blood glucose in the brain. Serum glucose levels were thought to regulate memory storage processes in an inverted-U-shaped fashion.

Brown and Kulik (1977) developed their flashbulb memory hypothesis, borrowing the potent mechanism from Livingston's (1967a,b) Now Print! theory. According to this view, the response to a significant event follows a three-stage process. First there is the recognition of novelty or unexpectedness (distinctiveness), followed by a test for biological significance, and then the "permanent registration of not only the significant novelty, but all recent brain events" (Brown and Kulik, 1977, p. 76). This is accomplished, according to Livingston, through diffuse action of the reticular formation. MacKay's binding hypothesis (MacKay et al., 2004) provides yet another perspective: in some of the other views expressed above, emotional stimuli soak up encoding resources. Specifically, through the action of the amygdala, the hippocampus binds word meanings to the context in which they occur.

Several researchers have proposed multistage processing of emotional stimuli. For example, Christianson (1992a,b) proposed a two-stage model wherein an emotional stimulus may automatically receive preferential processing, followed by elaborative processing of the stimulus. Fabiani and Donchin (1995) argued that working memory maintains a model of recent experience or context. The P300 response to distinctive stimuli reflects the updating of that model resulting from the necessity reorganizing the experience. If a stimulus requires this update, then it is marked, and the marking can be used to aid retrieval processes.

An obvious criticism of the emotional distinctiveness view is its extensive coverage of responses from the mild surprise of encountering a red word printed in a list of black words to the shock and horror one experiences at the loss of a loved one. Are the mechanisms proposed above (e.g., attention focusing, brain glucose, contextual binding) qualitatively the same across a continuum of emotional reactions, perhaps differing only in magnitude with changes in emotional intensity? Or are qualitatively different memory processes invoked by each of the many emotions? Some researchers have attempted to separate manipulations associated with distinctiveness into different groups. Michelon and Snyder (2006) argued that the N400 cortical response was seen with manipulations of secondary distinctiveness, and the P300 associated with primary distinctiveness. However, only the P300 was consistently associated with good memory performance. Schmidt (2006, 2007) has argued for a categorization of stimuli into those that are distinctive and those that are significant. Within this view, distinctiveness is the result of a mismatch between an experience and memory representations, whereas the significance of an experience results from a match between the experience and previous significant experiences. Only significant stimuli were thought to lead to strong emotional responses and poor memory for surrounding stimuli.

#### 2.09.3.4 Hybrid Theories

Although there is considerable divergence across the three theoretical perspectives described above, there is also commonality. For example, theories of stimulus orientation (e.g., Ohman, 1979) often invoke a feature-matching process similar to representational theories of distinctiveness. Fabiani (2006) and Christianson (1992b) both describe poststimulus elaboration and rehearsal processing that are reminiscent of organizational theories of distinctiveness. Schmidt (1991; Schmidt and Saari, in press) developed the incongruity hypothesis, which contains elements of all three approaches.

According the incongruity hypothesis, each presented item is compared with the contents of working memory. If an item is encountered that contains features that substantially differ from the weighted features in working memory, then the observer orients to the item. This orientation is automatic and leads to the increased storage of features extracted from the item. Because the process is automatic, the incongruent item will not rob attentional resource from other items with the typically slow rates of presentation used in many memory experiments. Some effect may be observed, however, in RSVP tasks (Raymond et al., 1992). In a modification of this view, significant stimuli hold attentional resources during an emotional appraisal process

(Schmidt, 2002b; Schmidt and Saari, in press), disrupting processing of material in the spatial or temporal proximity of the significant item. Further processing of distinctive and significant experiences may occur as a result of controlled elaboration and organizational processes. The first two phases in the incongruity hypothesis clearly place the locus of the effects of distinctiveness on encoding processes. However, Schmidt (1991) also included a retrieval component: "during the memory test (Phase 3), the effect of incongruity on memory will depend on the degree to which stored information supports good memory performance" (p. 537).

There are several strengths of the incongruity hypothesis. First, the framework incorporates research concerning the effects of stimulus contrast on physiological measures of orientation and attention. Second, the framework includes an explanation of the effects of distinctiveness on organization in recall (e.g., Bruce and Gains, 1976). Third, the framework explains why the effects of secondary distinctiveness may be limited to within-subjects designs. However, some have argued that the incongruity hypothesis incorrectly predicts that the effects of primary distinctiveness should be reduced if the distinctive item is in the first serial position of the list (Hunt, 1995; McDaniel and Geraci, 2006). According to this view, the first item in a list cannot be incongruent, and thus should not stand out at retrieval. However, this interpretation of the incongruity hypothesis is overly simplistic. Increased attention to an item through incongruity has its impact on memory by increasing individual-item processing of the item. This increased processing then supports retrieval and discrimination processes, which lead to enhanced memory for the distinctive item. The first item in a list, because of its primacy position, should also lead to orientation and increased attention (Oberauer, 2003) relative to other items on the list. Thus, it is reasonable to assume that the same critical features will be encoded for the distinctive first item as are encoded for a distinctive middle item. In addition, feature selection during the encoding of subsequent list items will be aligned with the contrast to the first item. Memory advantages enjoyed by a distinctive first item should thus be similar to those of a distinctive middle item.

## 2.09.4 Empirical Phenomena

As indicated above, a large number of phenomena have been offered as examples of the effects of distinctiveness on memory, been explained by reference to the von Restorff effect, or been described as the result of distinctive processing. In the following section, I provide a brief description of many of these phenomena and attempt to cast them within the theoretical frameworks outlined above.

### 2.09.4.1 von Restorff's Original Work

von Restorff's (1933) original paper has been summarized elsewhere (Hunt, 1995); in addition, there is a very readable and accessible translation of her paper available online (see Hunt, 1995). However, given that her research is very unlike what most people think of as the von Restorff effect (e.g., Wikipedia, 2006), it is worth recounting some of her original work.

von Restorff described a series of experiments investigating proactive and retroactive interference effects in recall and recognition. In some of her experiments, she employed a collection of diverse objects (e.g., a number, a green square, a letter, a nonsense syllable). Some of the objects were massed, that is, four objects of the same type (e.g., four nonsense syllables) appeared in the list, and others were isolated, in that only one object of a specific type appeared in the list. She demonstrated that memory for isolated items exceeded memory for massed items. In another of her experiments, von Restorff contrasted memory for three lists: one number with nine nonsense syllables, one syllable with nine numbers, and a list of ten heterogeneous items (a number, a syllable, a button, a chemical compound, etc.). The proportion of isolated items recalled greatly exceeded the proportion of common items from the same list. She also demonstrated that isolated numbers or syllables were more likely to be recalled, and were more quickly recalled, than were numbers or syllables from the heterogeneous list. However, the difference between recall of an isolated item and recall of the same item from the heterogeneous list was smaller than the difference between the isolated item and the common items in the same list. Across experiments, she varied the structure of the lists, as well as the position of the isolated item. She concluded that similar list items were absorbed into the memory trace field, whereas isolated items were not. von Restorff reported these effects in recall and recognition, but the effects were larger in recall. Finally, she concluded that both proactive and retroactive interference were the result of these same field effects.

#### 2.09.4.2 The Isolation Effect

Numerous researchers have adapted the design of the second von Restorff experiment described in the preceding section. In these experiments, a single isolated item (e.g., a word printed in red) is placed in a list of otherwise homogeneous items (printed in black). Memory for this item is then compared to memory for the same item in a list of homogeneous items (all words printed in black). Typically, recall of the isolated word would exceed recall of the same word printed in black (Rabinowitz and Andrews, 1973). This design focuses on one of the more striking findings reported by von Restorff and provides a purer measure of isolation. That is, in von Restorff's design, one cannot separate the positive effect of isolation on memory for the isolated item from potential negative effects of isolation on memory for the remainder of the list. In a well-designed experiment, memory for a physically identical stimulus can be either assessed with that stimulus isolated or not, and potential positive and negative effects of isolation can be identified (e.g., Schmidt, 1985). Wallace (1965) provided a detailed review of early isolation effect experiments; Schmidt (1991) provided a brief review of more recent research. Good memory for isolated items can be found with both physical and semantic isolation and is observed on recall, recognition, and even implicit tests (Geraci and Rajaram, 2004) of memory. The presence of an isolated item in a list impairs recall but not recognition of other items on the list (Schmidt, 1985). Because of its central place within distinctiveness research, all three theoretical perspectives described here have been applied to the isolation effect.

#### 2.09.4.3 Bizarre Imagery and the Bizarreness Effect

Memorists have long believed that bizarre imagery is an effective mnemonic device (Yates, 1966). However, experimental tests of the benefits of bizarre imagery led to an inconsistent and confusing array of results. This confusion was greatly alleviated when McDaniel and Einstein (1986) conclusively demonstrated a bizarreness advantage in the recall of sentences. They demonstrated that the bizarreness effect was only obtained when participants experienced both bizarre and common sentences within the same experimental context. Thus was born the distinctiveness interpretation of the bizarre imagery effect.

It is beyond the scope of this chapter to review the vast literature on bizarre imagery effect. Additional coverage can be found in the Mental Imagery chapter in this volume (*See* Chapter 2.08), and a recent review of the bizarreness effects can be found in Worthen (2006). Bizarreness appears to have both positive and negative effects on memory, aiding memory for the bizarre material but interfering with sentence integration (McDaniel and Einstein, 1986) and retention of order information (DeLosh and McDaniel, 1996). As a result, the positive bizarreness effect is usually confined to free-recall tests and not found on cued-recall (see Einstein and McDaniel, 1987, for a review), ordered-recall (DeLosh and McDaniel, 1996), or recognition (McDaniel and Einstein, 1986) tests of memory performance. There are currently two prominent explanations for these effects, one from the organizational and one from the representational perspectives outlined in section 2.09.3. From the organizational perspective, bizarreness encourages individual-item processing at the expense of relational processing and the processing of order information (DeLosh and McDaniel, 1996). In contrast, McDaniel et al. (2000, 2005) have argued against differential processing interpretations of the bizarreness effect. Rather, the bizarreness benefit occurs at retrieval when the set of features used during retrieval "are functionally distinctive in the context of the retrieval set"(McDaniel et al., 2005, p. 271). It is unclear how to reconcile this position with the list order effects reported by McDaniel and Geraci (2006), described in Section 2.09.2.

#### 2.09.4.4 The Humor Effect

Humorous material is often remembered better than nonhumorous material matched in content (Kaplan and Pascoe, 1977; Kintsch and Bates, 1977; Schmidt, 1994; Schmidt and Williams, 2001). Like the bizarreness effect, humorous material only has a mnemonic advantage in mixed-lists designs. Also, similar to the bizarreness effect, the humor effect is eliminated if the humorous material is presented in a block prior to the nonhumorous material in the same list (Guynn et al., as reported in McDaniel and Geraci, 2006). Unlike the bizarreness effect, the humor effect is obtained in cued recall (Schmidt, 1994). This is probably because humorous sentences are easily integrated, whereas bizarreness disrupts sentence continuity. Schmidt (2002a) provided a hybrid explanation of the humor effect. He concluded that humorous cartoons received increased attention and discrimination processes in a mixed list and were given retrieval priority during the memory test.

### 2.09.4.5 The Serial Position Curve and Temporal Distinctiveness

Memory performance for a series of presented items is often a U-shaped function of input position, with participants showing good memory for the beginning and ending of the series and relatively poor memory for the middle positions. This ubiquitous phenomenon has led to numerous explanations, but it is most often cast within the modal model (i.e., Atkinson and Shiffrin, 1968) and the fate of items in sensory, short-term, and long-term memory (Crowder, 1976). However, Murdock (1962) suggested a different cause in his seminal paper on the shape of the serial position curve. He argued that the shape of the curve resulted from retroactive and proactive interference between adjacent items on the list. In addition, Murdock (1960) applied his distinctiveness model to the bowed serial position curve. Recently, researchers have returned to the distinctiveness explanation of the serial position curve (Nairne et al., 1997; Neath, 1993) within the representational view described above. Surprenant (2001) applied this approach to the memory of tonal sequences and, true to the von Restorff tradition, argued that a common theory of relative distinctiveness could be applied to both perceptual and memory phenomena.

The distinctiveness interpretation of the serial position curve also has its opponents. Rouder and Gomez (2001) argued that the temporal distinctiveness parameters used to model the serial position curve were arbitrary. Oberauer (2003) argued that an attentional gradient was necessary to account for the primacy effect. Lewandowsky et al. (2006) argued for an event-based rather then a temporal-based account of the curve. Within this view, the temporal structure of the list (beginning, end, inserted pauses, etc.) provides opportunities for consolidation, rehearsal, and organizational processes. These processes are responsible for the shape of the serial position curve, not temporal distinctiveness per se. Note that one could still use the concept of distinctiveness to explain the serial position curve within this framework. However, item distinctiveness would be event or item based and not tied to the memory representation of the temporal gradient.

### 2.09.4.6 Orthographic Distinctiveness

Zechmeister (1972) was one of the first researchers to report that orthographically uncommon words (e.g., 'llama') are remembered better than words that conform to common English orthography. This effect has been found on recall (Hunt and Mitchell, 1982), recognition (Zechmeister, 1972), and word fragment completion (Hunt and Toth, 1990) tests of memory. However, like many of the effects of distinctiveness, the orthographic distinctiveness effect appears to be confined to mixed-list designs (Hunt and Elliot, 1980). Interestingly, the effects of orthographic distinctiveness are additive with the effects of conceptual distinctiveness (Hunt and Mitchell, 1982; Kirchhoff et al., 2005), and thus orthographic and conceptual distinctiveness may be mediated by different mechanisms (Kirchhoff et al. 2005).

Geraci and Rajaram (2002) argued that the orthographic distinctiveness effect is only obtained on implicit memory tests if the participants are aware of the relation between the test and the encoding task. In addition, orthographic distinctiveness effects were reduced if the participants' attention was divided between two tasks. They suggested that conceptual processing of the relation between the distinctive and common items is important to produce the effect. Geraci and Rajaram concluded that their results were consistent with Hunt's distinctiveness hypothesis, as well as Schmidt's (1991) incongruity idea, and the Fabiani and Donchin (1995) framework described above.

### 2.09.4.7 The Word Frequency Effect

Recall of frequent words usually exceeds recall of infrequent words. In contrast, recognition memory for infrequent words usually exceeds that for frequent words (Gregg, 1976). The word-frequency effect in recognition is often cast within a representational view of item distinctiveness. That is, low-frequency words appear in fewer preexperimental encodings than high-frequency words. In terms of Eysenck's framework described above, it should be relatively easy to discriminate between the low-frequency word's experimental and preexperimental encodings (Brown, 1976; Eysenck and Eysenck, 1980), leading to higher hit rates and lower false alarm rates for low- than for high-frequency words (Rao and Proctor, 1984). Superior recognition of low-frequency words is found in both homogeneous and mixed lists (see Gregg, 1976, for a review), as well as with implicit memory tests (MacLeod and Kampe, 1996). Eysenck and Eysenck (1980) provided support for the distinctiveness interpretation by demonstrating that distinctive processing (e.g., producing an infrequent modifier for the nouns in the study) reduced the word-frequency effect in recognition.

The word-frequency effect in recall has been cast within the individual item/relational processing view of distinctiveness (DeLosh and McDaniel, 1996; Dobbins et al., 1998; Saint-Aubin and LeBlanc, 2005). DeLosh and McDaniel (1996) argued that memory for word order plays an important role in many recall tasks. In addition, encoding "resources are lured to processing and interpreting the individual and idiosyncratic features of unusual items" (DeLosh and McDaniel, 1996, p. 1137). This shift in encoding robs resources from processing order information. In a pure list of high-frequency words, there are greater resources to devote to order processing than in a pure list of infrequent words, leading to the typical recall advantage found for the high-frequency words. However, in a mixed list of high- and low-frequency words, increased processing of the low-frequency words takes place at the expense of the order encoding of both types of words. The low-frequency words received increased individual item processing relative to the high-frequency words, and both types of items suffer from a disruption of order encoding or relational processing. The result is that in the recall of mixed lists, low-frequency words are sometimes recalled better than high-frequency words (Delosh and McDaniel, 1996; Saint-Aubin and LeBlanc, 2005). DeLosh and McDaniel demonstrated this reversal, as well as the predicted effect of mixed lists on memory for order information.

Saint-Aubin and LeBlanc (2005) also compared memory for pure and mixed lists of high- and low-frequency words. They employed relatively short lists of words and a serial order recall task. In their mixed lists, a single high- or low-frequency word was isolated in lists of five words of the other type. My interpretation of the order-encoding hypothesis leads me to predict that a single high-frequency item should be poorly recalled in the context of infrequent words. That is, the infrequent words should rob encoding processes from the high-frequency word. However, the high-frequency words were recalled better than the low-frequency words in this list structure. In addition, there was not a significant effect of word frequency when the lists contained primarily high-frequency items. These results seem to challenge the order-encoding interpretation of the word-frequency effect. Interestingly, Saint-Aubin and LeBlanc (2005) argued that their results supported a distinctiveness interpretation, citing Hulme et al.'s (2004) explanation of the word-length effect. According to Saint-Aubin and LeBlanc, high-frequency words were more distinctive than low-frequency words.

### 2.09.4.8 The Word Length Effect

On immediate-recall tests, recall of short words often exceeds recall of long words. This finding is often interpreted within a working memory model and the role of the phonological loop in immediate recall (Baddeley et al., 1975). However, the word-length effect is also found with delayed tests, and with lists that should exceed the memory span (Russo and Grammatopoulou, 2003), challenging the working memory interpretation of the effect. Three different distinctiveness interpretations of the word-length effect have been offered as alternatives to the working memory hypothesis. Hulme et al. (2004) argued that the word-length effect was in reality an effect of item complexity. Short items are less complex than long items and, thus, are less susceptible to memory errors (Neath and Nairne, 1995). In addition, because short items contain fewer features than long items, they will share fewer features across other list items. As a result, short items have greater item distinctiveness within the Neath representational framework. Hulme et al. used this framework to explain the absence of a word-length effect in mixed lists of long and short words alternating across input positions.

Cowan et al. (2003) also evaluated the word-length effect in mixed lists, but they varied the number of long and short words in the list and compared memory with and without articulatory suppression. The word-length effect was either reversed (without articulatory suppression) or eliminated (with articulatory suppression) when the list was composed of primarily short words. The typical word-length effect was obtained when the list was predominately long words. They concluded that in mixed lists, organizational factors play an important role in recall, invoking the organizational view of distinctiveness.

Hendry and Tehan (2005) investigated the word-length effect in mixed lists and employed both serial recall and recognition measures of memory performance. They observed the typical short word advantage on the recall task, but long words were recognized better than short words. They interpreted their results with DeLosh and McDaniel's (1996) order-encoding hypothesis (see section 2.09.3.1). That is, long words rob encoding resources from the processing of order information, impairing serial recall, but, long words also benefit from increased item processing relative to short words, leading to greater recognition of long words than short words. From this perspective, long words are more distinctive than short words.

### 2.09.4.9 The Concreteness Effect

"Concrete language is remembered better than abstract language in a wide variety of tasks" (Paivio et al., 1994, p. 1196). The concreteness effect is most often interpreted within Paivio's (1971) dual-coding theory, according to which imaginal and verbal processing independently contribute to memory for concrete words, whereas only verbal processing is usually possible for abstract material. The concreteness effect is found in both within- and between-subjects designs (Marschark and Hunt, 1989). Nonetheless, Marschark and Hunt (1989) noted that the concreteness effect was greatly attenuated in free recall and argued that this challenged the dual-coding interpretation. Instead, they cast the concreteness effect within the individual item/relational-processing framework (see also Marschark, 1985, and Marschark and Surian, 1992). Within this view, concrete materials encourage encoding of perceptual attributes of the material that can serve a distinctive function at retrieval.

It is worth noting that both views of the concreteness effect include the role of item distinctiveness (Paivio et al., 1994). What appears to be at issue is whether or not separate memory codes for verbal and imaginal processing is a necessary component of an explanation of the concreteness effect. According to the dual-coding theory, the additive effects of concreteness and relatedness on memory performance implicate independent contributions of the two systems. In contrast, Marschark and Hunt (1989) argued that concreteness effects in recall should only be observed in the presence of relational processing. That is, the distinctive memory representations of concrete words cannot contribute to good memory performance if the search set cannot be identified by appropriate relational information. Paivio et al. (1994) and Richardson (2003) have challenged this assertion by reporting additive effects of concreteness and relatedness. However, ter Doest and Semin (2005) found a concreteness effect on an explicit word stem completion test for a list of related words but not for a list of unrelated words, providing support for the Marschark and Hunt position. Nonetheless, a concreteness effect was observed for the unrelated word list in their free-recall test. Clearly, neither dual coding nor distinctiveness by themselves provides complete explanations of the concreteness effect. Both perspectives rely on other mechanisms (e.g., task-appropriate processing, Hamilton and Rajaram, 2001) to handle the full range of phenomena.

### 2.09.4.10 The Picture Superiority Effect

Under many conditions, including in both mixed- and between-list designs, people remember pictures better than they remember words (see Paivio, 1971, 1986). Research concerning this picture superiority effect parallels research on the concreteness effect in several ways. Like the concreteness effect, early explanations of the picture superiority effect were cast within Paivio's (1971) dual-coding hypothesis. The dual-coding explanation was then challenged by a distinctiveness explanation (Nelson et al., 1976; Nelson, 1979), and the distinctiveness explanation was then given further support by studies employing implicit memory tests (Weldon and Coyote, 1996; Hamilton and Geraci, 2006). Despite these similarities, the concreteness effect has been cast within an individual item/relational processing view of distinctiveness, whereas the picture superiority effect has been cast within a representational view of distinctiveness.

Nelson's (1979) conceptualization of distinctiveness is very similar to that of Eysenck (1979) and other representational views of distinctiveness. "Retention level is assumed to be a direct function of the relatively unique and unified nature of the study trial encoding *and* [author's emphasis] the degree to which the retrieval environment recapitulates this encoding" (Eysenck, 1979: p. 49). From this view, pictures have more unique (distinctive) features than words. Words presented in a list are limited by font and letter constraints that render them visually similar. In contrast, a picture of an object may contain many features that help distinguish it from pictures of other objects appearing on a list. Evidence for this perspective was found in the fact that the picture superiority effect could be diminished, or even reversed, by employing pictures that were visually similar to one another (Nelson et al., 1976). This explanation of the picture superiority effect has faired better than empirical tests of the individual item/relational explanation of the concreteness effect. Perhaps the concreteness effect should be recast within the Nelson/Eysenck view of distinctiveness. That is, perhaps concrete words encourage visual imagery processes, and the resulting images are more distinctive than the verbal representations of abstract words (Hamilton and Rajaram, 2001).

### 2.09.4.11 False Memory and the Distinctiveness Heuristic

Research concerning the distinctiveness heuristic trades heavily on the picture superiority effect. Israel and Schacter (1997) investigated memory within the Deese-Roediger and McDermott false memory paradigm (Roediger and McDermott, 1995; *See* Chapter 2.14). In this paradigm, a list of related words, for example, bed, rest, awake, and dream, is followed by a memory test. Of interest is participants' false memory for a related target word, such as 'sleep' Israel and Schacter compared memory for words spoken and written to words spoken and depicted in pictures. Picture presentation led to lower false recognition than written presentation. The authors argued that distinctive perceptual qualities of the pictures, features not available following written word presentation, served to reduce false memory. Schacter et al. (1999) later developed the idea of a distinctiveness heuristic: "a mode of responding based on participants' metamemorial awareness that true recognition of studied items should include recollection of distinctive details" (Schacter et al., 1999, p. 3). Schacter, Dodson, and associates have provided impressive support for the use of the distinctiveness heuristic (e.g., Schacter et al., 2001; Dodson and Schacter, 2001, 2002).

Hege and Dodson (2004) provided an alternative explanation for the lower false memories for pictures than for words. According to this view, the distinctive nature of pictures leads to impaired relational processing relative to the processing of printed text. As a test of this hypothesis, Hege and Dodson compared both recall and recognition memory following picture and word presentations. On the recall test, participants were asked to report any items related to the studied list, presumably bypassing any use of the distinctiveness heuristic. In support of the individual item/relational view, participants were still less likely to commit false recall of the target items following the picture than following the word presentation. On a follow-up recognition test, participants were instructed to put check marks next to items that actually appeared on the memory lists. Support for the distinctiveness heuristic was found when false recognition was lower for pictures then for words. Additional support for the distinctiveness heuristic was reported by Dodson and Hege (2005). In this study, the researchers varied the rate of presentation of test items on the recognition test. On self-paced tests, pictures lead to lower rates of false memories than words. However, on fast-paced tests (750 ms/item), the pictures and words led to comparable false recognition rates. In contrast, true recognition rates for words and pictures were similar, and both declined equally as the test pace increased. These results provide evidence against the idea that the low rate of false recognition of pictures results from reduced relational processing relative to words. Rather, the authors invoked two-stage theories of recognition (e.g., McElree et al., 1999; *See* Chapter 2.23) and argued that the distinctiveness heuristic is a time-consuming retrieval processes. As a result, lower false memories for pictures than for words only occurs during slow-paced recognition tests.

The distinctiveness heuristic should confound those of us studying distinctiveness and memory for several reasons. First, the idea presupposes that participants have the metamemorial abilities to discern which mnemonic variables are likely to increase and decrease the distinctiveness of memories. Given the literature reviewed here, it is clear that memory researchers do not agree on how variables impact item distinctiveness. Attributing this knowledge to the typical research participant is questionable at best. Second, the argument begins with the explicit assumption that pictures are more distinctive than words. Whereas there is research to support this claim, it is not an incontrovertible fact and, according to Nelson et al. (1976), depends on the pictures. Third, the Dodson and Hege (2005) results seem to undermine the whole enterprise. Not only do these results challenge the idea that words receive greater relational processing than pictures but they challenge the idea that the memory representations of pictures are more distinct than the memory representations of words. More distinctive memories should lead to greater true and lower false recognitions independent of the pace of the recognition test (from a representational view of distinctiveness). Nonetheless, the proportion of both hits and false alarms for pictures were equal to those of words on the fast-paced test. Perhaps the picture superiority effect results from dual coding, and the distinctive memory traces referred to by the distinctiveness heuristic are stored in Paivio's imagery system. During the recognition test, participants may need to access this visual code to aid memory discrimination processes. It is well established that accessing a visual code for verbally presented materials requires time (Paivio and Csapo, 1969). If this dual-coding interpretation is correct, then the picture superiority effect on both true and false memories may tell us more about dual coding than about item distinctiveness.

### 2.09.4.12 Face Recognition

Recognition memory for unfamiliar faces is greatly influenced by face uniqueness (Going and Reed, 1974), distinctiveness (Cohen and Carr, 1975), or typicality (Light et al., 1979). Going and Reed (1974) attributed this effect to the fact that a greater number of eye fixations were devoted to unique than to common visual stimuli. Cohen and Carr (1975) argued that the effect was akin to the von Restorff effect, whereas Light et al. (1979) attributed the effect to interitem similarity. The most comprehensive treatment of the effect of facial distinctiveness on recognition has been offered by Valentine and his associates (Valentine and Bruce, 1986; Valentine, 1991; Valentine and Ferrara, 1991).

Valentine has argued that faces are represented in a multidimensional space, with typical faces represented near the conceptual core of the category and atypical faces located at the categorical fringe. Valentine and Bruce (1986) argued that participants detected that an atypical face was different from the category norm, and this led to distinctive encodings of these faces. However, they concluded that "[t]he exact nature of a mechanism which may give rise to the effect of distinctiveness of encoding is unclear" (Valentine and Bruce, 1986, p. 304). Valentine and Ferrara (1991) were more specific in that they modeled facial recognition within both the McClelland and Rumelhart (1985) distributed memory theory and Nosofsky's (1986) model of item recognition. In the McClelland and Rumelhart theory, connection weights were determined by the difference between an input face and the facial prototype. Within the Nosofsky framework, the atypical face is not given special treatment at encoding. Rather, the distinctive memory representation of the atypical trace aids discrimination processes in recognition memory. Valentine (1991), again adopted a representational view, and argued that distance in the multidimensional space supported discrimination processes in face recognition. Typical faces fall in a crowded region of space, whereas atypical faces fall in less densely populated regions, aiding item discrimination processes in recognition.

It is worth noting that research concerning facial memory relies on subjective ratings of facial typicality or distinctiveness. Memory performance is usually tested over a range of stimuli differing in distinctiveness, and then either memory is correlated with the measure of distinctiveness (e.g., Valentine and Bruce, 1986) or a median split is used to group faces into distinctive and common groups (e.g., Newel et al., 1999). In other words, researchers always seem to employ a mixed-list presentation of common and distinctive items. Valentine's (1991) theory implies that the effects of facial distinctiveness should occur in between-list manipulation of facial type as well. It would be nice to see an empirical demonstration of this prediction.

### 2.09.4.13 The Modality Effect

Auditory presentation of verbal material often leads to superior memory performance than visual presentation. This effect is more robust on tests of immediate memory than on tests of delayed memory (Penney, 1989). The immediate memory modality effect is often attributed to the beneficial effects of a separate auditory sensory store (Crowder and Morton, 1969). However, both the immediate-memory modality effect (Nairne, 1990) and the long-term modality effect (Conway and Gathercole, 1987) have been attributed to item distinctiveness. Conway and Gathercole have shifted their view of the role of distinctiveness in the long-term modality effect. Conway and Gathercole (1987) and Gathercole and Conway (1988) argued that auditory stimuli were temporally more distinct than visual stimuli. Conway and Gathercole (1990) argued for a translation processes, wherein translation from one input domain to another (e.g., voicing a visually presented word) led to a more distinctive memory representation than processing in one domain. Nairne (1990) argued that visual presentation led to primarily modality-independent memory representations, whereas auditory presentation created both modality-independent and modality-specific memory representation. The modality-specific representations available following auditory presentation provide distinctive features to aid memory performance. Nairne's model has been used to explain an impressive range of phenomena, including modality, suffix, and serial position effects, as well as the impacts of articulatory suppression and irrelevant speech on memory performance (see Neath and Surprenant, 2003).

Recent research into the phenomenon of false memory (*See* Chapter 2.14) has led to an interesting twist in the interpretation of the modality effect. Smith and Hunt (1998) found that visual presentation led to fewer false memories in the Deese-Roediger and McDermott paradigm (see Roediger and McDermott, 1995) than did auditory presentation. They also demonstrated that a task designed to increase distinctive processing (pleasantness rating) reduced false memories. They concluded that visual presentation led to more distinctive memory representations than auditory presentation. Gallo et al. (2001) replicated and extended these findings to both within- and between-subject manipulations of modality. Furthermore, auditory presentation only led to greater false memories on visual tests of recognition memory. They concluded that participants use a list-specific heuristic, wherein distinctive visual cues retained from visually presented words aid discrimination between old and new items on the memory test.

It is hard to reconcile these views of the modality effect in false memory with the Conway and Gathercole (1990) and Nairne (1990) explanations of the modality effect in immediate recall. The false memory research is more consistent with the view of the modality effect developed by Penney (1989). She argued for separate streams of processing for visually and auditorily presented information. Visual information led to a rapidly fading visual code and a phonological code, whereas auditory information led to a more persistent acoustic code plus a phonological code. As a result, visual inputs are associated based on simultaneous presentation, whereas auditory information is integrated across time. Similarly, Arndt and Reder (2003) argued that auditory presentation encouraged relational processing across items, whereas visual presentation encouraged individual item (i.e., distinctive) processing (see also, Pierce et al., 2005). Thus, in order to explain enhanced memory following auditory presentation, and lower false memory following visual presentation, the modality effect has been recast from the original representational view to the individual item/relational processing view of distinctiveness.

### 2.09.4.14 Emotional Words

Researchers have long argued that emotional material is remembered better than neutral material (Kleinsmith and Kaplan, 1963, 1964; Maltzman et al., 1966). However, several researchers have noted that the effect may depend on experimental design (Walker and Tarte, 1963). Most of the early research investigating memory for emotional material employed mixed lists of emotional and neutral words. When memory for a homogeneous list of emotional words has been compared to a memory for a homogeneous list of neutral words, the emotional memory effect sometimes disappears (Dewhurst and Parry, 2000; Hadley and MacKay, 2006). Dewhurst and Parry (2000) argued that the mixed-list presentation enhanced the distinctiveness of the emotional words; however, they do not specify how this happens. Perhaps they have in mind a trade-off between individual-item and relational processing.

However, a distinctiveness interpretation of the emotional memory effect is complicated by the fact that not all emotional words have the same impact on memory and attention processes. Words associated with sex and the bathroom have a greater impact on memory than do less offensive words (Manning and Goldstein, 1976), and the emotional memory effect is larger for negative than for positively valenced emotional words (McNulty and Isnor, 1967; Dewhurst and Parry, 2000). Furthermore, Saari and Schmidt (2005) found an emotional memory effect for taboo words in both within- and between-subjects designs. In contrast, with negative affect non-taboo words, an emotional memory effect was only found when mixed-list designs were employed (Schmidt and Saari, in press).

The complex relation between word emotion and memory will likely require a hybrid explanation that includes both a representational view of distinctiveness and shifts in attentional resources. Schmidt and Saari (in press) noted that emotional words often lead to increased attention as measured by the Stroop color-naming task (see Williams et al., 1996, for a review). However, Schmidt and Saari found that emotional Stroop effect was modulated by both list structure and the type of emotional words employed. With taboo words, the emotional Stroop effect was found in both mixed- and pure list designs and was of equal magnitude in both designs. In addition, the memory advantage for taboo words occurred in both list structures but was larger in the mixed list design. This suggests that taboo words attract extra encoding resources in both experimental designs but benefit from item distinctiveness in a within-list design. A different pattern of results was found with nontaboo emotional words. With nontaboo words, the Stroop effect was only found with relatively short interstimulus intervals (ISIs) and when the emotional and neutral words were presented in blocks. The Stroop effect for these nontaboo words was thus probably the result of carryover in the processing of one emotional word to the processing of the next word in the series (see also McKenna and Sharma, 2004). In contrast with the Stroop effect, enhanced memory only occurred in mixed list with these emotional nontaboo words, and the memory effect was independent of ISI or blocking. Thus, increased attention was not related to good memory for the nontaboo emotional words. Instead, these words gained their mnemonic salience from a distinctive retrieval context. Schmidt and Saari concluded that increased attention and a distinctive retrieval context work together to produce enhanced recall of taboo words, whereas with nontaboo emotional words, the emotional memory effect is the result of item distinctiveness. Thus, the results were compatible with the Schmidt (1991) incongruity hypothesis and the Fabiani and Donchin (1995) orientation-distinctiveness view.

### 2.09.4.15 Odor

Several researchers have reported that odor is a very effective retrieval cue (the so-called Proust phenomenon; Chu and Downes, 2002; Herz and Schooler, 2002). However, some researchers have failed to find that odor cues facilitate memory (Bjork and Richardson-Klavehn, 1989). Herz (1997) argued that for an odor cue to be effective, the odor must be salient in the environment. That is, the odor cue must be distinctive, or contextually inappropriate, in the experiment. Thus, the positive effects of odor on memory may be tied to cue-distinctiveness within an Eysenck framework of the effects of distinctiveness on memory.

## 2.09.5 Summary and Conclusions

Based on this review, one is tempted to conclude that the concept of distinctiveness in memory research is amorphous and has been utilized to explain such a wide range of phenomena that it is nearly bankrupt. Within the same phenomenon, completely opposing roles of distinctiveness have been proposed. For example, some researchers have argued that low-frequency words are more distinctive than high-frequency words, whereas others have argued that high-frequency words are more distinctive than low-frequency words (see also the word-length effect). Auditory presentation apparently leads to a more distinctive memory representation than visual presentation, unless of course you are discussing false memory, in which case visual presentation leads to more distinctive memory representations than auditory presentations. Within the same phenomenon, many different distinctiveness interpretations have been offered (e.g., the bizarreness effect, the word length effect, the concreteness effect). And, with conceptually and empirically similar phenomena (e.g., the concreteness effect and the picture superiority effect), distinctiveness explanations have taken different forms.

Schmidt (1991) also noted the varied forms of the distinctiveness hypothesis, leading him to ask: "Can we have a distinctive theory of memory?" (Schmidt, 1991, p. 523). There are several answers to this question. One answer is that the concept of distinctiveness can be used heuristically, or descriptively. In this approach, good memory implies distinctiveness. That is, distinctiveness is not really a theory of good memory but a description of why memory is good. Unfortunately, many researchers continue to use distinctiveness in this manner (see Hunt, 2006, for a similar complaint).

Alternatively, one can look for a coherent structure in the phenomena reviewed in this chapter and use that structure to narrow the theoretical and empirical fields. With very few exceptions, the effects of distinctiveness are modulated by experimental design. The notable exceptions include the word frequency effect in recognition, the concreteness effect, the picture superiority effect, and memory for taboo words. These phenomena occur in both between- and within-subject designs. It is tempting to attribute these select phenomena to mechanisms other than distinctiveness (i.e., familiarity, dual coding, and emotional processing, respectively). The remaining phenomena, those more naturally tied to distinctiveness, either disappear in between-list designs (e.g., bizarre imagery effect) or simply must be studied in within-subjects designs (e.g., the isolation effect and the serial position curve). Any successful theory of distinctiveness must explain the impact of experimental design on the pattern of results.

As another general observation, encoding as well as retrieval processes are nearly always a part of successful explanations of distinctiveness. The word-frequency effect in recognition is the only notable exception to this rule. However, Chunyan et al. (2004) noted an association between the late-positive ERP and the correct recognition of low-frequency words – implicating encoding processes in the word-frequency effect. Diana and Reder (2006) also provided support for the role of encoding processes in the word-frequency effect in recognition. These researchers compared memory following either single-task (study the list) or dual-task (study the list while engaging in an addition task) encoding conditions. Performing the dual task during encoding eliminated the effect of word frequency on hit rates and reduced the effect on false alarm rates relative to single-task performance.

Of the 15 different memory phenomena reviewed herein, ten have been explained by specific reference to representational models. I caution against this view as an exclusive explanation of the effects of distinctiveness on memory. Representational views generally overlook encoding processes, and as I have argued, encoding plays an important role in modulating many of the effects of distinctiveness. Representational theories have defined distinctiveness in terms of a memory (or memory trace plus retrieval cue) representation that shares few features with other memory representations. Support for this assumption is found in the fact that recognition of distinctive items exceeds memory for typical items. Without some independent index of item distinctiveness, this explanation provides little insight into memory processes. (Note that this criticism does not apply to the distinctiveness explanation of the serial position curve, where position or time serves as a parameter in calculating item distinctiveness.) Schmidt (1995) provided evidence against representational approaches to category typicality effects on memory, and his criticism applies to representational approaches to secondary distinctiveness effects in general. Finally, the representational view implies a strong causal link between distinctiveness and memory. According to this view, the psychological space is relatively empty around distinctive items, and each distinctive item in a list should also be off by itself within this space. As a result, it should not matter if a list has 20 such distinctive items or ten common items and ten distinctive items. In both cases, each distinctive item should fall in a relatively empty psychological spatial region, leading to enhanced item discrimination processes relative to the common items found in crowded regions. Thus, distinctive memory representations should enhance memory in both mixed-list and between-subjects designs. In addition, distinctive memories should aid performance on intentional, incidental, and implicit tests of memory. Of the phenomena reviewed above, only the concreteness effect, the picture-superiority effect, and the word-frequency effect in recognition meet these standards. All of the other phenomena require additional explanatory mechanisms.

In order to avoid tautological explanations of memory performance, specific definitions of distinctiveness must be employed. These definitions must be supported by converging evidence. That is, if I say that A is more distinctive than B, and that item distinctiveness supports better memory for A than B, then I must independently demonstrate both halves of this assertion. In addition, theories of distinctiveness should provide specific mechanisms whereby distinctiveness aids memory performance. From the above review, we can see that the list of potential mechanisms is not long. The list includes increased attention (as indexed by neurological or behavioral correlates), increased item processing at the expense of relational processing, feature sampling, ease of discrimination, and retrieval priority.

These observations lead me to conclude that adequate theories of distinctiveness will necessarily be hybrid models of the kind proposed by Schmidt (1991), Christianson (1992a,b), Fabiani and Donchin (1995), Worthen et al. (1998), and some instantiations of the individual item/relational processing framework. Within each of these approaches, there is a clear definition of what is "distinctive" – they describe specific mechanisms whereby distinctiveness enhances memory, they include both encoding and retrieval components, and they can be applied across a range of empirical phenomena. In addition, these theories help to integrate physiological measures of attention and arousal with behavioral measures of attention and memory. The extended power of these approaches is also their drawback, for it is hard to make predictions concerning how distinctiveness should influence memory performance in specific situations.

In summary, the concept of distinctiveness has become chameleonic, as researchers color and stretch it in attempts to gain insight into a broad range of memory phenomena. Three different theoretical perspectives concerning distinctiveness can be identified: organizational theories, representational theories, and affective theories. The definition of distinctiveness, and the explanations for how it influences memory, vary across these perspectives and from one empirical phenomenon to another. As a result, there is a danger that distinctiveness will be relegated to little more than a description of good memory performance.

However, theories that describe specific mechanisms whereby distinctiveness influences performance have been proposed and do explain an impressive range of findings. Hybrid models that include organizational processes, emotional processes, and encoding and retrieval processes, as well as incorporating some of the ideas from representational views, appear the most promising.

## References


Arndt J and Reder LM (2003) The effect of distinctive visual information on false recognition. *J. Mem. Lang.* 48: 1–15.

Atkinson RC and Shiffrin RM (1968) Human memory: A proposed system and its control processes. In: Spence KW and Spence JT (eds.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 2, pp. 89–195. New York: Academic Press.

Baddeley AD, Thomson N, and Buchanan M (1975) Word length and the structure of short-term memory. *J. Verb. Learn. Verb. Behav.* 14: 375–389.

Bjork RA and Richardson-Klavehn A (1989) On the puzzling relationship between environmental context and human memory. In: Izawa C (ed.) *Current Issues in Cognitive Processes*, pp. 313–344. Hillsdale, NJ: Lawrence Erlbaum Associates.

Bower GH (1992) How might emotions affect learning? In: Christianson S-A (ed.) *The Handbook of Emotion and Memory: Research and Theory*, pp. 3–31. Hillsdale, NJ: Erlbaum.

Brown J (1976) An analysis of recognition and recall and of problems in their comparison. In: Brown J (ed.) *Recall and Recognition*, pp. 1–34. New York: Wiley.

Brown R and Kulik J (1977) Flashbulb memories. *Cognition* 5: 73–99.

Bruce D and Gaines MT (1976) Tests of an organizational hypothesis of isolation effects in free recall. *J. Verb. Learn. Verb. Behav.* 15: 59–72.

Burke A, Heuer F, and Reisberg D (1992) Remembering emotional events. *Mem. Cognit.* 20: 277–290.

Christianson S-A (1992a) Emotional stress and eyewitness memory: A critical review. *Psychol. Bull.* 112: 284–309.

Christianson S-A (1992b) Remembering emotional events: potential mechanisms. In: Christianson S-A (ed.) *The Handbook of Emotion and Memory: Research and Theory*, pp. 307–340. Hillsdale, NJ: Erlbaum.

Chu S and Downes JJ (2002) Proust nose best: Odors are better cues of autobiographical memory. *Mem. Cognit.* 30: 511–518.

Chunyan G, Ying Z, and Jinhong D (2004) An event-related potential study on the relationship between encoding and stimulus distinctiveness. *Acta Psychol. Sinica* 36: 455–463.

Cohen ME and Carr WJ (1975) Facial recognition and the von Restorff effect. *Bull. Psychon. Soc.* 6: 383–384.

Conway MA and Gathercole SE (1987) Modality and long-term memory. *J. Mem. Lang.* 26: 341–361.

Conway MA and Gathercole SE (1990) Writing and long-term memory: Evidence for a 'translation' hypothesis. *Q. J. Exp. Psychol. A: Hum. Exp. Psychol.* 42: 513–527.

Cowan N, Baddeley AD, Elliott EM, and Noriss J (2003) List composition and the word length effect in immediate recall: A comparison of localist and globalist assumptions. *Psychon. Bull. Rev.* 10: 74–79.

Craik FIM and Tulving E (1975) Depth of processing and the retention of words in episodic memory. *J. Exp. Psychol. Gen.* 104: 268–294.

Crowder RG (1976) *Principles of Learning and Memory*. Hillsdale, NJ: Lawrence Erlbaum.

Crowder RG and Morton J (1969) Precategorical acoustic storage (PAS) *Percept. Psychophys.* 5: 365–373.

Darwin C (1872) *The Expression of the Emotions in Man and Animals*. New York: D Appleton.

DeLosh EL and McDaniel MA (1996) The role of order information in free recall: Application to the word-frequency effect. *J. Exp. Psychol. Learn. Mem. Cogn.* 22: 1136–1146.

Dewhurst SA and Parry LA (2000) Emotionality, distinctiveness, and recollective experience. *Eur. J. Cogn. Psychol.* 12(4): 541–551.

Diana RA and Reder LM (2006) The low-frequency encoding disadvantage: Word frequency affects processing demands. *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 805–815.

Dobbins IG, Kroll NE, Yonelinas AP, and Liu Q (1998) Distinctiveness in recognition and free recall: The role of recollection in the rejection of the familiar. *J. Mem. Lang.* 38: 381–400.

Dodson CS and Hege ACG (2005) Speeded retrieval abolishes the false-memory suppression effect: Evidence for the distinctiveness heuristic. *Psychon. Bull. Rev.* 12: 726–731.

Dodson CS and Schacter DL (2001) ''If I had said it I would have remembered it'': Reducing false memories with a distinctiveness heuristic. *Psychon. Bull. Rev.* 8: 155–161.

Dodson CS and Schacter DL (2002) When false recognition meets metacognition: The distinctiveness heuristic. *J. Mem. Lang.* 46: 782–803.

Easterbrook JA (1959) The effect of emotion on cue utilization and the organization of behavior. *Psychol. Rev.* 66: 183–201.

Einstein GO and McDaniel MA (1987) Distinctiveness and the mnemonic benefits of bizarre imagery. In: McDaniel MA and Pressly M (eds.) *Imagery and Related Mnemonic Processes: Theories, Individual Differences, and Applications*, pp. 78–102. New York: Springer-Verlag.

Ellis NR, Detterman DK, Runcie D, McCarver RB, and Craig E (1971) Amnesic effects in short-term memory. *J. Exp. Psychol.* 89: 357–361.

Eysenck MW (1979) Depth, elaboration, and distinctiveness. In: Cermak LS and Craik FIM (eds.) *Levels of Processing in Human Memory*, pp. 89–118. Hillsdale, NJ: Erlbaum.

Eysenck MW and Eysenck MC (1980) Effects of processing depth, distinctiveness, and word frequency on retention. *Br. J. Psychol.* 71: 263–274.

Fabiani M (2006) Multiple electrophysiolgical indices of distinctiveness. In: Hunt RR and Worthen JB (eds.) *Distinctiveness and Memory*, pp. 339–360. Oxford: University Press.

Fabiani M and Donchin E (1995) Encoding processes and memory organization: A model of the von Restorff effect. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 224–240.

Fabiani M, Gratton G, and Coles MGH (2000) Event-related brain potentials: Methods, theory and applications. In: Cacioppo J, Tarrinary L, and Berntson G (eds.) *Handbook of Psychophysiology*, pp. 53–84. New York: Cambridge University Press.

Gallo DA, McDermott KB, Percer JM, and Roediger HL (2001) Modality effects in false recall and false recognition. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 339–353.

Gathercole SE and Conway MA (1988) Exploring long-term modality effects: Vocalization leads to best retention. *Mem. Cognit.* 16: 110–119.

Gati I and Ben-Shakhar G (1990) Novelty and significance in orientation and habituation: A feature-matching approach. *J. Exp. Psychol. Gen.* 119: 251–263.

Gati I and Tversky A (1984) Weighting common and distinctive features in perceptual and conceptual judgments. *Cognit. Psychol.* 16: 341–370.

Geissler H-G (2001) After the revolutions of gestalt and action control theories: Is there a psychophysics of task-related structural representations? A discussion based upon evidence from visual categorization. Fechner Day 2001. In: Sommerfeld R, Kompass T, and Lachmann (eds.) *Proceedings of the Seventeenth Annual Meeting of the International Society of Psychophysics*, pp. 2–16. Lengerich: Pabst Science Publishers.

Geraci L and Rajaram S (2002) The orthographic distinctiveness effect on direct and indirect tests of memory: Delineating the awareness and processing requirements. *J. Mem. Lang.* 47: 273–291.

Geraci L and Rajaram S (2004) The distinctiveness effect in the absence of conscious recollection: Evidence from conceptual priming. *J. Mem. Lang.* 51: 217–230.

Going M and Reed JD (1974) Effects of uniqueness, sex of subject, and sex of photograph on facial recognition. *Percept. Motor Skills* 39: 109–110.

Gold P (1987) Sweet memories. *Am. Sci.* 75: 151–155.

Gold P (1992) A proposed neurobiological basis for regulating memory storage for significant events. In: Winograd E and Neisser U (eds.) *Affect and Accuracy in Recall: Studies of ''Flashbulb'' Memories*, pp. 141–161. New York: Cambridge University Press.

Gregg VH (1976) Word frequency, recognition, and recall. In: Brown J (ed.) *Recall and Recognition*, pp. 183–215. London: Wiley.

Hadley CB and MacKay DG (2006) Does emotion help or hinder immediate memory? Arousal versus priority-binding mechanisms. *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 79–88.

Hamilton M and Geraci L (2006) The picture superiority effect in conceptual implicit memory: A conceptual distinctiveness hypothesis. *Am. J. Psychol.* 119: 1–20.

Hamilton M and Rajaram S (2001) The concreteness effect in implicit and explicit memory tests. *J. Mem. Lang.* 44: 96–117.

Hege ACG and Dodson CS (2004) Why distinctive information reduces false memories: Evidence for both impoverished relational-encoding and distinctiveness heuristic accounts. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 787–795.

Hendry L and Tehan G (2005) An item/order trade-off explanation of word length and generation effects. *Memory* 13: 364–371.

Herz RS (1997) The effects of cue-distinctiveness on odor-based context-dependent memory. *Mem. Cognit.* 25: 375–380.

Herz RS and Schooler JW (2002) A naturalistic study of autobiographical memories evoked by olfactory and visual cues: Testing the proustian hypothesis. *Am. J. Psychol.* 115: 21–32.

Hirshman E, Whelley MM, and Palij M (1989) An investigation of paradoxical memory effects. *J. Mem. Lang.* 28: 594–609.

Hulme C, Surprenant AM, Bireta TJ, Stuart G, and Neath I (2004) Abolishing the word-length effect. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 98–106.

Hunt RR (1995) The subtlety of distinctiveness: What von Restorff really did. *Psychon. Bull. Rev.* 2: 105–112.

Hunt RR (2006) The concept of distinctiveness in memory research. In: Hunt RR and Worthen JB (eds.) *Distinctiveness and Memory*, pp. 3–25. Oxford: University Press.

Hunt RR and Einstein GO (1981) Relational and item-specific information in memory. *J. Verb. Learn. Verb. Behav.* 20: 497–514.

Hunt RR and Elliott JM (1980) The role of nonsemantic information in memory: Orthographic distinctiveness effects on retention. *J. Exp. Psychol. Gen.* 109: 49–74.

Hunt RR and Lamb CA (2001) What causes the isolation effect? *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 1359–1366.

Hunt RR and McDaniel MA (1993) The enigma of organization and distinctiveness. *J. Mem. Lang.* 32: 421–445.

Hunt RR and Mitchell DB (1978) Specificity in nonsemantic orienting tasks and distinctive memory traces. *J. Exp. Psychol. Hum. Learn. Mem.* 4: 121–135.

Hunt RR and Mitchell DB (1982) Independent effects of semantic and nonsemantic distinctiveness. *J. Exp. Psychol. Hum. Learn. Mem.* 8: 81–87.

Hunt RR and Toth JP (1990) Perceptual identification, fragment completion, and free recall: Concepts and data. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 282–290.

Israel L and Schacter DL (1997) Pictorial encoding reduces false recognition of semantic associates. *Psychon. Bull. Rev.* 4: 577–581.

James W (1890/1950) *The Principles of Psychology*. New York: Dover.

Johnston CD and Jenkins JJ (1971) Two more incidental tasks that differentially affect associative clustering in recall. *J. Exp. Psychol.* 89: 92–95.

Kaplan RM and Pascoe GC (1977) Humorous lectures and humorous examples: Some effects upon comprehension and retention. *J. Educ. Psychol.* 69: 61–65.

Kintsch W and Bates E (1977) Recognition memory for statements from a classroom lecture. *J. Exp. Psychol. Learn. Mem. Cogn.* 3: 150–159.

Kirchhoff BA, Schapiro ML, and Buckner RL (2005) Orthographic distinctiveness and semantic elaboration provide separate contributions to memory. *J. Cogn. Neurosci.* 17: 1841–1854.

Kleinsmith LJ and Kaplan S (1963) Paired-associate learning as a function of arousal and interpolated activity. *J. Exp. Psychol.* 65: 190–193.

Kleinsmith LJ and Kaplan S (1964) Interaction of arousal and recall interval in nonsense syllable paired-associate learning. *J. Exp. Psychol.* 67: 124–126.

Lewandowsky S, Brown GDA, Wright T, and Nimmo LM (2006) Timeless memory: Evidence against temporal distinctiveness models of short-term memory for serial order. *J. Mem. Lang.* 54: 20–38.

Light LL, Kayra-Stuart F, and Hollander S (1979) Recognition memory for typical and unusual faces. *J. Exp. Psychol. Hum. Learn. Mem.* 5: 212–228.

Livingston RG (1967a) Brain circuitry relating to complex behavior. In: Quarton GC, Melnechuck T, and Schmitt FO (eds.) *The Neurosciences: A Study Program*, pp. 499–514. New York: Rockefeller University Press.

Livingston RG (1967b) Reinforcement. In: Quarton GC, Melnechuck T, and Schmitt FO (eds.) *The Neurosciences: A Study Program*, pp. 568–576. New York: Rockefeller University Press.

Loftus EF and Burns TE (1982) Mental shock can produce retrograde amnesia. *Mem. Cognit.* 10: 318–323.

MacKay DG, Shafto M, Taylor JK, Marion DE, Abrams L, and Dyer J (2004) Relations between emotion, memory and attention: Evidence from taboo Stroop, lexical decision, and immediate memory tasks. *Mem. Cognit.* 32: 474–488.

MacLeod CM and Kampe KE (1996) Word frequency effects on recall, recognition, and word fragment completion tests. *J. Exp. Psychol. Learn. Mem. Cogn.* 22: 132–142.

Maltzman I, Kantor W, and Langdon B (1966) Immediate and delayed retention, arousal and defensive reflexes. *Psychon. Sci.* 6: 445–446.

Manning SK and Goldstein FD (1976) Recall of emotional and neutral words as a function of rate and organization of list presentation. *J. Gen. Psychol.* 95: 241–249.

Marschark M (1985) Imagery and organization in the recall of prose. *J. Mem. Lang.* 24: 734–745.

Marschark M and Hunt RR (1989) A reexamination of the role of imagery in learning and memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 710–720.
Marschark M and Surian L (1992) Concreteness effects in free recall: The roles of imaginal and relational processing. *Mem. Cognit.* 20: 612–620.
McCabe DP, Presmanes AG, Robertson CL, and Smith AD (2004) Item-specific processing reduces false memories. *Psychon. Bull. Rev.* 11: 1074–1079.
McClelland JL and Rumelhart DE (1985) Distributed memory and the representation of general and specific information. *J. Exp. Psychol. Gen.* 114: 159–188.
McCloskey M, Wible C, and Cohen N (1988) Is there a special flashbulb memory mechanism? *J. Exp. Psychol. Gen.* 117: 171–181.
McDaniel MA and Einstein GO (1986) Bizarre imagery as an effective memory: The importance of distinctiveness. *J. Exp. Psychol. Learn. Mem. Cogn.* 12: 54–65.
McDaniel MA and Geraci L (2006) Encoding and retrieval processes in distinctiveness effects: Toward an integrative framework. In: Hunt RR and Worthen JB (eds.) *Distinctiveness and Memory*, pp. 65–88. Oxford: Oxford University Press.
McDaniel MA, DeLosh EL, and Merritt PS (2000) Order information and retrieval distinctiveness: Recall of common versus bizarre material. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1045–1056.
McDaniel MA, Dornburg C, and Guynn MJ (2005) Disentangling encoding versus retrieval explanations of the bizarreness effect: Implications for distinctiveness. *Mem. Cognit.* 33: 270–279.
McElree B, Dolan PO, and Jacoby LL (1999) Isolating the contributions of familiarity and source information to item recognition: A time course analysis. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 563–582.
McKenna FP and Sharma K (2004) Reversing the emotional Stroop effect reveals that it is not what it seems: The role of fast and slow components. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 382–392.
McNulty JA and Isnor CJ (1967) Affective connotation of words as a factor in free recall learning. *Br. Psychol. Soc.* 58: 51–56.
Medin DL, Goldstone RL, and Gentner D (1993) Respects for similarity. *Psychol. Rev.* 100: 254–278.
Michelon P and Snyder AZ (2006) Neural correlates of incongruity. In: Hunt RR and Worthen JB (eds.) *Distinctiveness and Memory*, pp. 361–380. Oxford: University Press.
Murdock BB (1960) The distinctiveness of stimuli. *Psychol. Rev.* 67: 16–31.
Murdock BB (1962) The serial position effect of free recall. *J. Exp. Psychol.* 64: 482–488.
Murdock BB (1972) Short-term memory. In: Bower GH and Spence JT (eds.) *The Psychology of Learning and Motivation,* vol. 5, pp. 67–127. New York: Academic Press.
Murdock BB (1974) *Human Memory: Theory and Data*. Hillsdale, NJ: Erlbaum.
Murphy GL and Medin DL (1985) The role of theories in conceptual coherence. *Psychol. Rev.* 92: 289–316.
Nairne JS (1990) A feature model of immediate memory. *Mem. Cognit.* 18: 251–269.
Nairne JS (2006) Modeling distinctiveness: Implications of general memory theory. In: Hunt RR and Worthen JB (eds.) *Distinctiveness and Memory*, pp. 27–46. Oxford: Oxford University Press.
Nairne JS, Neath I, Serra M, and Byun E (1997) Positional distinctiveness and the ratio rule in free recall. *J. Mem. Lang.* 37: 155–166.
Neath I (1993) Distinctiveness and serial position effects in recognition. *Mem. Cognit.* 21: 689–698.
Neath I and Nairne JS (1995) Word-length effect in immediate memory: Overwriting trace-decay theory. *Psychon. Bull. Rev.* 2: 429–441.
Neath I and Surprenant AM (2003) *Human Memory: An Introduction to Research, Data, and Theory.,* 2nd edn. Belmont, CA: Wadsworth.
Nelson DL (1979) Remembering pictures and words: Appearance, significance and name. In: Cermak LS and Craik FIM (eds.) *Levels of Processing in Human Memory*, pp. 45–76. Hillsdale, NJ: Erlbaum.
Nelson DL, Reed VS, and Walling JR (1976) The pictorial superiority effect. *J. Exp. Psychol. Hum. Learn. Mem.* 2: 523–528.
Newel FN, Chiroro P, and Valentine T (1999) Recognizing unfamiliar faces: The effects of distinctiveness and view. *Q. J. Exp. Psychol. A: Hum. Exp. Psychol.* 52A: 509–534.
Nosofsky RM (1986) Attention similarity, and the identification-categorization relationship. *J. Exp. Psychol. Gen.* 115: 39–57.
Oberauer K (2003) Understanding serial position curves in short-term recognition and recall. *J. Mem. Lang.* 49: 469–483.
Ohman A (1979) The orienting response, attention, and learning: An information-processing perspective. In: Kimmell HD, van Olst EH, and Orlebeke JE (eds.) *The Orienting Reflex in Humans*, pp. 443–471. Hillsdale, NJ: Erlbaum.
Paivio A (1971) *Imagery and Verbal Processes*. New York: Holt Rinehart and Winston.
Paivio A (1986) *Mental Representation: A Dual Coding Approach*. Hillsdale, NJ: Erlbaum.
Paivio A and Csapo K (1969) Concrete-image and verbal memory codes. *J. Exp. Psychol.* 80: 279–285.
Paivio A, Walsh M, and Bons T (1994) Concreteness effects on memory: When and why? *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 1196–1204.
Penney CG (1989) Modality effects and the structure of short-term verbal memory. *Mem. Cognit.* 17: 398–422.
Pierce BH, Gallo DA, Weiss JA, and Schacter DL (2005) The modality effect in false recognition: Evidence for test-based monitoring. *Mem. Cognit.* 33: 1407–1413.
Rabinowitz FM and Andrews SR (1973) Intentional and incidental learning in children and the von Restorff effect. *J. Exp. Psychol.* 100: 315–318.
Rajaram S (1996) Perceptual effects on remembering: Recollective processes in picture recognition memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 22: 365–377.
Rao K and Proctor RW (1984) Study-phase processing and the word frequency effect in recognition memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 10: 386–394.
Raymond JE, Shapiro KL, and Arnell KM (1992) Temporary suppression of visual processing in an RSVP task: An attentional blink? *J. Exp. Psychol. Hum. Percept. Perform.* 18: 849–860.
Richardson JTE (2003) Dual coding versus relational processing in memory for concrete and abstract words. *Eur. J. Cognit. Psychol.* 15: 481–509.
Roediger HL and McDermott KB (1995) Creating false memories: Remembering words not presented in lists. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 803–814.
Rouder JN and Gomez P (2001) Modelling serial position curves with temporal distinctiveness. *Memory* 9: 301–311.
Rundus D (1971) Analysis of rehearsal processes in free recall. *J. Exp. Psychol.* 89: 63–77.
Russo R and Grammatopoulou N (2003) Word length and articulatory suppression affect short-term and long-term recall tasks. *Mem. Cognit.* 31: 728–737.
Saari B and Schmidt SR (2005) *The Effects of Taboo Words on Memory.* Paper presented at the annual meeting of the South Eastern Psychological Association, Nashville TN.

Saint-Aubin J and LeBlanc J (2005) Word frequency effects in immediate serial recall of pure and mixed lists: Tests of the associative link hypothesis. *Can. J. Exp. Psychol.* 59: 219–227.
Schacter DL, Israel L, and Racine C (1999) Suppressing false recognition in younger and older adults: The distinctiveness heuristic. *J. Mem. Lang.* 40: 1–24.
Schacter DL, Cendan DL, Dodson CS, and Clifford ER (2001) Retrieval conditions and false recognition: Testing the distinctiveness heuristic. *Psychon. Bull. Rev.* 8: 827–833.
Schmidt SR (1985) Encoding and retrieval processes in the memory for conceptually distinctive events. *J. Exp. Psychol. Learn. Mem. Cogn.* 11: 565–578.
Schmidt SR (1991) Can we have a distinctive theory of memory? *Mem. Cognit.* 19: 523–542.
Schmidt SR (1994) Effects of humor on sentence memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 953–967.
Schmidt SR (1996) Category typicality effects in episodic memory: Testing models of distinctiveness. *Mem. Cognit.* 24: 595–607.
Schmidt SR (2002a) The humor effect: Differential processing and privileged retrieval. *Memory* 10: 127–138.
Schmidt SR (2002b) Outstanding memories: The positive and negative effects of nudes on memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 28: 353–361.
Schmidt SR (2006) Emotion, significance, distinctiveness, and memory. In: Hunt RR and Worthen JB (eds.) *Distinctiveness and Memory*, pp. 47–64. Oxford: Oxford University Press.
Schmidt SR (2007) Unscrambling the Effects of Emotion and Distinctiveness on Memory. In: Nairne J (ed.) *The Foundations of Remembering. Essays in Honor of Henry L. Roediger, III*, pp. 141–158. New York: Psychological Press.
Schmidt SR and Saari B (in press) The Emotional Memory Effect: Differential Processing or Item Distinctiveness? *Mem. Cognit*.
Schmidt SR and Williams AR (2001) Memory for humorous cartoons. *Mem. Cognit.* 29: 305–311.
Shepard RN (1987) Toward a universal law of generalization for psychological science. *Science* 237: 1317–1323.
Smith RE and Hunt RR (1998) Presentation modality affects false memory. *Psychon. Bull. Rev.* 5: 710–715.
Sokolov EN (1963) *Perception and the conditioned reflex*. New York: Macmillan.
Surprenant AM (2001) Distinctiveness and serial position effects in tonal sequences. *Percept. Psychophys.* 63: 737–745.
ter Doest L and Semin GR (2005) Retrieval contexts and the concreteness effect: Dissociations in memory for concrete and abstract words. *Eur. J. Cogn. Psychol.* 17: 859–881.
Tversky A (1977) Features of similarity. *Psychol. Rev.* 84: 327–352.
Valentine T (1991) A unified account of the effects of distinctiveness, inversion and race in face recognition. *Q. J. Exp. Psychol.* 43A: 161–204.
Valentine T and Bruce V (1986) Recognizing familiar faces: The role of distinctiveness and familiarity. *Can. J. Psychol.* 40: 300–305.
Valentine T and Ferrara A (1991) Typicality in categorization, recognition and identification: Evidence from face recognition. *Br. J. Psychol.* 82: 87–102.
Van Overschelde JP, Rawson KA, Dunlosky J, and Hunt RR (2005) Distinctive processing underlies skilled memory. *Psychol. Sci.* 16: 358–361.
Von Restorff H (1933) Uber die Virkung von Bereichsbildungen im Spurenfeld. *Psychol. Forsch.* 18: 299–342.
Walker EL and Tarte RD (1963) Memory storage as a function of arousal and time with homogeneous and heterogeneous lists. *J. Verb. Learn. Verb. Behav.* 2: 113–119.
Wallace WP (1965) Review of the historical, empirical, and theoretical status of the von Restorff phenomenon. *Psychol. Bull.* 63: 410–424.
Weldon MS and Coyote KC (1996) Failure to find the picture superiority effect in implicit conceptual memory tests. *J. Exp. Psychol. Learn. Mem. Cogn.* 22: 670–686.
Wikipedia (2006) Von Restorff effect. http://en.wikipedia.org/wiki/Von_Restorff_effect. Accessed 4 July 2007.
Williams JMG, Mathews A, and MacLeod C (1996) The emotional Stroop task and psychopathology. *Psychol. Bull.* 120: 3–24.
Worthen JB (2006) Resolution of discrepant memory strengths: An explanation of the effects of bizarreness on memory. In: Hunt RR and Worthen JB (eds.) *Distinctiveness and Memory*, pp. 133–156. Oxford: Oxford University Press.
Worthen JB, Marshall PH, and Cox KB (1998) List length and the bizarreness effect: Support for a hybrid explanation. *Psychol. Res.* 61: 147–156.
Yates FA (1966) *The Art of Memory*. Chicago: University of Chicago Press.
Zechmeister EB (1972) Orthographic distinctiveness as a variable in word recognition. *Am. J. Psychol.* 85: 425–430.

# 2.10 Mnemonics: Underlying Processes and Practical Applications

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In modern society, we rely on accurate memories to perform a variety of tasks throughout the day. We must remember passwords and user names while using the Internet, account and personal identification numbers for business transactions, and myriad telephone numbers for use both at work and at home. Even a mundane event such as a trip to the grocery store is dependent on accurate memory. Such a trip involves not only remembering what to buy at the store but also how to get to the store, the name and a few personal details of the chatty neighbor who will invariably end up next to us in the checkout line, and where the car is parked when we have completed our shopping. Clearly, we rely heavily on our memory system to negotiate the modern world. However, the reliance on memory for successful adaptation to the environment is not a product of modernity at all. In fact, the development of strategies to enhance memory – referred to as mnemonics – dates backs thousands of years. When all communication relied primarily on the oral tradition, the ancient Greeks and Romans developed strategies for remembering lengthy speeches and poems (Yates, 1966), and medieval lawyers used mnemonics to memorize entire sets of codes and laws (Fentress and Wickham, 1992). In fact, good memory was considered a virtue in medieval Europe, and mnemonic training was fundamental to medieval education (Carruthers, 1990). Thus, it appears that the desire to improve one's memory has a history that long predates the formal study of psychology. In this chapter, we describe some of the most popular and enduring techniques for enhancing memory and discuss the cognitive principles that are believed to underlie each technique.

## 2.10.1 Mnemonic Processes

Although numerous techniques and strategies have been offered to improve memory, the vast majority of mnemonics represent simple applications of basic research findings in cognitive psychology. In fact, the most popular mnemonic techniques are designed to capitalize on a few well-researched psychological processes: organization, elaboration, and mental imagery. Because of their fundamental importance to mnemonic strategies, we briefly discuss each of these processes next.

#### 2.10.1.1 Organization

A major function of mnemonics is organization of to-be-remembered information. It has been clearly established that organized information is easier to remember than unorganized information (Jenkins and Russell, 1952; Bower et al., 1969; Broadbent et al., 1978) and that instructions to organize information enhances memory even in the absence of instructions to memorize (Mandler, 1967). It is also widely accepted that both episodic and semantic information is stored in long-term memory in an organized fashion (e.g., Smith et al., 1974; Collins and Loftus, 1975; Raaijmakers and Shiffrin, 1981; Anderson, 1983; Tulving, 1983). Moreover, examinations of recall output indicate that learners will subjectively organize information that is presented randomly (Bousefield, 1953), even if that information is, on the surface, unrelated (Tulving, 1962). Thus, it is likely that the organization function of mnemonics decreases storage demands by arranging the stimuli in a fashion that more closely matches the preexisting organizational structure of long-term memory. Furthermore, mnemonics that link the to-be-remembered information to the organizational structure of long-term memory may also facilitate retrieval (Baddeley, 1990).

#### 2.10.1.2 Elaboration

A second major process used in the context of mnemonics is elaboration. Although the term is sometimes used synonymously with semantic analysis in textbooks (e.g., Matlin, 2005), an accurate definition describes elaboration more generally as a process of embellishment with additional information (Baddeley, 1990; Anderson, 1995). The advantage of the latter definition is that it allows for a distinction to be made between meaningful and nonmeaningful elaboration. A good deal of research (e.g., Craik and Tulving, 1975; Rogers et al., 1977; Nelson, 1979) supports the notion that meaningful elaboration enhances memory. However, nonmeaningful elaboration can also enhance memory, and under certain conditions, it can do so better than meaningful elaboration (Slamecka and Graf, 1978; Kolers, 1979; Pressley et al., 1987). Thus, it appears that it is the degree of elaboration induced by a mnemonic rather than its meaningfulness that facilitates memory (cf. Craik and Tulving, 1975).

It is also important to note how elaboration facilitates memory. It is believed that elaboration facilitates memory by making memories more discriminable at retrieval by virtue of distinctive processing (Craik, 1979; Lockhart et al., 1976). Distinctive processing is defined as the processing of difference in the context of similarity (Hunt, 2006). As it relates to mnemonics, this suggests that, by way of elaboration, a mnemonic adds uniquely identifying or item-specific information to to-be-remembered items. As a result of additional item-specific information, mnemonic-enhanced memories are more discriminable than memories of unelaborated items at retrieval.

#### 2.10.1.3 Mental Imagery

Some of the most enduring mnemonics involve the use of mental imagery as a form of elaboration. The term mental imagery can be used to refer to any type of mental representation (e.g., Kosslyn et al., 1990; Intons-Peterson, 1992), but in the context of mnemonics, mental imagery is usually visual. A wealth of research (e.g., Paivio et al., 1968; Paivio, 1969; Bower, 1970; May and Clayton, 1973; Richardson, 1978) supports the notion that visual mental imagery enhances memory, and this effect is especially robust when interactive imagery is used (Wollen et al., 1972; Yesavage et al., 1983). Mental imagery is an effective component of mnemonics because it has the potential to enhance both the organization and elaboration of to-be-remembered information. Thus, the use of interactive visual imagery in mnemonics may serve to facilitate the encoding and storage of to-be-remembered information as well as it making the information more discriminable at retrieval.

The use of bizarre mental imagery as a component of mnemonics has been advocated by Greek and Roman orators (Yates, 1966), professional mnemonists (Lorayne and Lucas, 1974; Lorayne, 1990, 1998), and educators (Tess et al., 1999). As a result, the relative effectiveness of bizarre and common imagery has received a good deal of attention from psychological researchers. Empirical research suggests that instructions to use bizarre imagery can lead to better memory than instructions to use common imagery when both types of imagery are used (McDaniel and Einstein, 1986; Cornoldi et al., 1988; Worthen and Marshall, 1996) and either free recall or recognition is tested (Worthen, 2006). However, additional research (Anderson and Buyer, 1994; Weir and Richman, 1996; Worthen, 1997) indicates that the bizarreness advantage is due to the more general process of bizarre elaboration rather than mental imagery *per se*. Regardless, it is likely that the use of bizarre elaboration in the context of a mnemonic makes the to-be-remembered information more discriminable at retrieval.

#### 2.10.1.4 Retrieval Cues

As described earlier, organization, elaboration, and mental imagery are often treated as part of the encoding process. However, one could just as easily suggest that these processes are part of the retrieval process. Indeed, as Tulving (1983) convincingly argued, any distinction between encoding and retrieval processes is purely heuristic. Processes occurring at the time of learning exert their effect on the retrieval process, either as facilitation or interference, and thus no meaningful theoretical dichotomy between encoding and retrieval remains coherent. The challenge is to explain the influence of processing at the time of initial experience on processes required for successful test performance. To this point, we have hinted at the importance of developing cues that are diagnostic of the to-be-remembered information. A more elaborate rendition of this idea is that the processing of the original experience, when reinstated at testing, constrains production to a limited set of items. This idea has been suggested to explain the effect of various encoding manipulations.

An example of this type of approach within the context of mnemonics is research (i.e., Wallace and Rubin, 1991; Rubin, 1995) that has examined the use of rhyme and meaning to cue memory for narratives in the oral tradition. Such research suggests that rhyme and meaning cues work in concert to facilitate memory by constraining the number of stored choices available at retrieval (cf. Rubin and Wallace, 1989). More generally, this notion of constraining choices at retrieval is at the heart of the effectiveness of distinctive processing. As noted by Hunt and Smith (1996), organization serves to specify the episodic context in which to-be-remembered information was embedded. The addition of item-specific information (e.g., a unique cue) along with organizational processing limits the retrieval set to items that both share the unique feature and were present in the specified context. Thus, processes that ostensibly occur during encoding may very well exert their influence by providing diagnostically precise cues at retrieval.

## 2.10.2 Formal Mnemonic Techniques

In this section, we discuss strategies for improving memory that involve highly prescribed instructions. Typically, formal mnemonics involve instructions for associating to-be-remembered information with more well-established stored memories.

#### 2.10.2.1 The Method of Loci

With evidence of its use dating back to circa 500 BC (Yarmey, 1984), the method of loci is perhaps the oldest enduring mnemonic. Believed to have been used extensively by Greek and Roman orators, the method of loci is designed to facilitate serial recall by organizing to-be-remembered information within the context of a well-established visual mental image. As an example, consider a herpetologist who wishes to use the method of loci to help remember the topics to be covered in a talk about venomous snakes in Texas. Specifically, the herpetologist wishes to discuss the five most common venomous snakes of Texas in order of potential dangerousness. From least to most dangerous, the snakes discussed in the talk would include the copperhead, the cottonmouth, the coral snake, the timber rattler, and the diamondback rattler. To use the method of loci to remember the list of species to be discussed, the herpetologist would first form a mental image of a very familiar place such as the layout of his home. The next step would be to form associations between the familiar image and the species of snakes to be discussed by mentally placing a cue representing each species in a separate part of the imagined location. In our example, the herpetologist might imagine the normally blue wooden front door of his house to be made of shiny copper to cue the memory of copperhead. Next, he might imagine a carpet of cotton balls (to cue cottonmouth) leading from the front door into the foyer. Similarly, to cue his memory for the coral snake, timber rattler, and diamondback rattler, the herpetologist could imagine a coffee table made of coral in the living room, a stand of small pine trees lining the stairwell, and an oversized diamond blocking passage at the top of the stairs. Finally, when the topics of the talk need to be recalled, the herpetologist would simply mentally revisit his familiar place and pick up the cues he left behind.

In theory, the method of loci should be an effective mnemonic because it represents an application of all three basic mnemonic processes. First, the to-be-remembered information is organized in a serial fashion by association with a well-established memory. In our herpetologist example, the necessary serial order of the list is maintained by associating the least dangerous species with the entrance to the home and the more dangerous species with more interior locations within the home. Thus, when the herpetologist mentally revisits his mental image at the time of his talk, he will encounter cues in the specified order simply by following the natural layout of his home.

Second, the method of loci provides elaboration of to-be-remembered information via the development of associated cues (e.g., pine trees for a timber rattler) and the use of visual mental imagery. One should also note that imagery used in our example was interactive and bizarre by design. The interactive nature of the imagery is important because it enhances the link between the well-established memory of the familiar place and the less-well-established memory of the to-be-remembered information. The bizarreness of the imagery allows the to-be-remembered information to stand out against the common backdrop and should ultimately lead to a more discriminable memory trace.

The effectiveness of the method of loci as mnemonic technique is supported by anecdotal evidence from professional mnemonists (Lorayne and Lucas, 1974), case studies of exceptional memories (Luria, 1968), and empirical evidence. Regarding the latter, research indicates that the method of loci indeed enhances serial recall (Ross and Lawrence, 1968; Christen and Bjork, 1976; Wang and Thomas, 2000), even after a substantial retention interval (Groninger, 1971; Wang and Thomas, 2000). Furthermore, research has demonstrated that the same loci can be used to learn several different lists without proactive interference (Christen and Bjork, 1976; de Beni and Cornoldi, 1988; Massen and Vaterrodt-Plunnecke, 2006). Some evidence also suggests that mnemonic training with the method of loci can curb some age-related memory differences in elderly adults (Hill et al., 1991; Brooks et al., 1999). Overall, the method of loci is considered along with the peg-word method (described next) to be one of the most effective mnemonics for learning lists (Roediger, 1980). However, when used to learn more complicated verbal material (e.g., prose, discourse), the method of loci is effective when to-be-remembered information is presented orally, but not when information is presented in a written format (Cornoldi and de Beni, 1991; Moe and de Beni, 2005). Additionally, because of its complexity, the method of loci is generally considered an unsuitable mnemonic for the rehabilitation of memory for those suffering from brain injury (McKinlay, 1992; Richardson, 1995).

#### 2.10.2.2 The Peg-Word Method

A mnemonic also designed to enhance serial learning, but with a less-storied history, is the peg-word method. Although its exact origins are unclear, the peg-word method may be a simplification of Grey's (1730) very complicated mnemonic system that involved the transformation of numbers to letters and sounds. Loosely similar to Grey's system, the peg-word method involves learning a list of words that rhyme with numbers to be used as framework with which to organize to-be-remembered items. In a typical rendering, the list of peg words includes bun, shoe, tree, door, hive, sticks, heaven, gate, wine, and hen to represent the numbers 1–10, respectively. To use the peg-word method, one first commits the list of peg words to memory. Then, when a list of items needs to be learned, an interactive visual image is formed between each to-be-remembered item and a peg word. As an example, suppose that an outdoor enthusiast wishes to remember a list of the most crucial items that one would need to survive in the wilderness. According to Bradley Angier's (1956) timeless book *How to Stay Alive in the Woods*, a minimal survival kit would include matches, a compass, a knife, a mirror, and maps. One could remember these items using the peg-word method by creating the following images: numerous matches protruding between two buns like a sloppy match sandwich, an animated compass wearing shoes (perhaps hiking boots!), a tree with a knife embedded in its trunk, a door with a mirror where the window should be, and an animated bee reading a map in front of a hive. When the items need to be remembered, one would simply recall the list of peg words in order. Just as the numbers 1–5 will cue memory for the peg words, the peg words should cue the list of needed items in a specific order.

Like the method of loci, the peg-word method makes use of organization, elaboration, and mental imagery. The association of to-be-remembered items to numbers allows the information to be organized in a specified sequence. The association of the to-be-remembered items to the peg words and the interactive mental image representing that association provides a good amount of elaboration to enhance the discriminability of the memory trace. Moreover, discriminability of the memory trace may be also be enhanced by the nearly inevitable use of bizarre elaboration when using the peg-word method.

Despite the apparent counterproductivity of learning one list (peg words) to remember another list (to-be-remembered items), the usefulness of the peg-word method has received a good deal of empirical support. Research has demonstrated the effectiveness of the method when used by normal and learning-disabled children (Veit et al., 1986; Krinsky and Krinsky, 1996), normal and learning-disabled adolescents (Elliot and Gentile, 1986), college-age adults (Wood, 1967; Bugelski, 1968; Bugelski et al., 1968; Johnson, 1970; Wood and Bolt, 1970; Wang and Thomas, 2000), and older adults (Wood and Pratt, 1987). The peg-word method has also been found to be effective after both short and lengthy retention intervals (Wang and Thomas, 2000). Furthermore, the same list of peg words can be used for numerous lists without interference (Morris and Reid, 1970; Massen and Vaterrodt-Plunnecke, 2006). However, the peg-word method has been demonstrated to be ineffective when used to learn information that is high in category relatedness (Reddy and Bellezza, 1986) or for information that is presented very rapidly (Bugelski et al., 1968). Also, like the method of loci, the peg-word method may be too complex for use with brain-injured learners in rehabilitation settings.

The relative effectiveness of the peg-word method, the method loci, and rote rehearsal in determining serial recall is depicted in **Figure 1**.

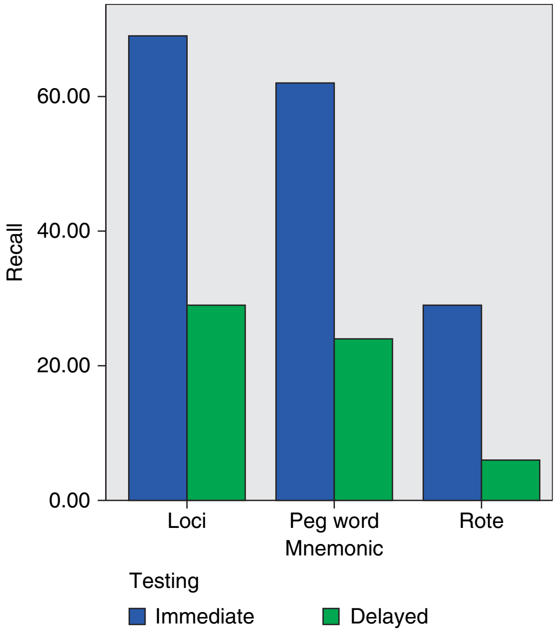


**Figure 1** Percentage of correct serial recall as a function of mnemonic method and retention interval. Adapted from Roediger HL (1980) The effectiveness of four mnemonics in ordering recall. *J. Exp. Psychol. Hum. Learn. Mem.* 6: 558–567.

### 2.10.2.3 The Keyword Method

The keyword method was originally developed by Raugh and Atkinson (1975) as a procedure to facilitate second-language acquisition. The keyword method involves making an association between a to-be-remembered term's meaning and what the term sounds like in one's primary language and then using interactive mental imagery to elaborate on that association. For example, consider an English speaker who is trying to learn the Spanish term queso, which means cheese in English. When pronounced, queso sounds like 'CASE-OH.' Thus, the learner could use the English word case as the keyword for remembering that queso means cheese. Forming a mental image of a briefcase made of cheese (or a briefcase full of cheese) could embellish the association between the keyword and the translation. At recall, the Spanish term queso should cue the keyword (case) and, subsequently, the interactive mental image that combined the meaning of the to-be-learned term and the keyword (i.e., briefcase made of cheese). From a theoretical perspective, the keyword method should be an effective mnemonic because it encourages elaboration during the production or processing of the keyword (depending on whether the learner generates the keyword) and because of its use of interactive mental imagery.

Empirical research has demonstrated the keyword method to be effective in facilitating second-language acquisition both in children (Pressley, 1981; Pressley et al., 1981) and adults (Atkinson and Raugh, 1975; Raugh and Atkinson, 1975; Beaton et al., 2005). The keyword method has also been found to facilitate primary-language vocabulary learning in learning-disabled children (Cundus et al., 1986; Mastropieri et al., 1990), normal children (Levin et al., 1992), and normal adults (Pressley, 1982; Sweeney and Bellezza, 1982; Troutt-Ervin, 1990). Additionally, versions of the keyword method have been used to effectively enhance children's learning of music history (Brigham and Brigham, 1998), adult's memory for artists and their work (Carney and Levin, 1991), the quality of college students' written essays (Rummel et al., 2003), and memory for prose in young, middle-aged, and elderly adults (Dretzke, 1993). However, a growing body of research (Wang et al., 1992, 1993; Wang and Thomas, 1995; Thomas and Wang, 1996) suggests that keyword method does not enhance recall after lengthy retention intervals (for contrary results, see McDaniel and Pressley, 1984; McDaniel et al., 1987). Research also indicates that the keyword method may not be effective for second-language acquisition among experienced foreign-language learners (van Hell and Mahn, 1997). Finally, regarding the keyword method, research (Campos et al., 2004; Beaton et al., 2005) suggests that the effectiveness of the method is dependent on mental-image quality.

### 2.10.3 Organizational Mnemonic Techniques

Organizational mnemonic techniques serve mainly to organize information such that all to-be-remembered information is linked together in memory. Unlike formal mnemonic techniques, organizational mnemonic techniques do not emphasize the establishment of associations between to-be-remembered information and previously stored memories to aid retrieval. Instead, organizational mnemonic techniques emphasize intralist associations and are thus less dependent on extralist cues for successful retrieval. Successful use of an organizational technique should consolidate all to-be-remembered information such that retrieval of one item cues memory for other items. Thus, like a connected chain of paper clips, successful retrieval of one item should result in successful retrieval of all items. However, a major disadvantage of this dependence on intralist cues is that the failure to retrieve a single item of the to-be-remembered information may result in the failure to recover all items cued by the forgotten item (cf. Bellezza, 1981, 1996).

#### 2.10.3.1 Acronyms (Linking by Initial Letter)

The use of acronyms to enhance free or serial recall is a popular mnemonic among college students (Gruneberg, 1973; Stalder, 2005). This method simply involves making a word or pseudo word out of the initial letters of to-be-remembered information. For example, a biology student might use the acronym IPMAT to remember the five stages of cell division (interphase, prophase, metaphase, anaphase, and telophase). Perhaps due to its simplicity and popularity among students, the use of acronyms has been advocated for learning a variety of information, including assessment criteria for psychological disorders (Short et al., 1992; Pinkofsky, 1997; Pinkofsky and Reeves, 1998).

Despite its simplicity and popularity, empirical research investigating the effectiveness of the use of acronyms as a mnemonic has provided minimal support for the method. Although a few studies (Nelson and Archer, 1972; Kovar and Van Pelt, 1991; Stalder, 2005) suggest limited effectiveness of acronyms as mnemonics, the bulk of research (Boltwood, and Blick, 1970; Waite et al., 1971; Perewiznyk and Blick, 1978; Carlson et al., 1981) suggests that acronyms do not enhance recall, especially when they are self-generated (Kibler and Blick, 1972).

#### 2.10.3.2 Linking by Story

Another way to organize to-be-remembered information such that all items are linked together is to form a story that incorporates each item. This method has the same organizational advantage of using acronyms but also includes a high degree of self-generated elaboration. Thus, unlike the use of acronyms, linking by story should result in a memory trace that both consolidates to-be-remembered items and is highly discriminable (cf. Bellezza, 1986).

Early empirical research investigating the linking-by-story mnemonic demonstrated the method to be effective for enhancing both serial (Bower and Clark, 1969) and free recall (Herrmann et al., 1973) of verbal material in college-age adults. Subsequent research has found the method to be useful for improving recall in elderly participants (Hill et al., 1991; Drevenstedt and Bellezza, 1993), memory-impaired participants (Wilson, 1995), and mildly retarded participants (Glidden, 1983). A variation of the linking-by-story method has also been found to improve memory for long strings of digits (Bellezza et al., 1992). Additionally, a study comparing the method of loci, the peg-word method, and the linking-by-story method found linking by story to be the most effective method to enhance free recall (Herrmann, 1987).

#### 2.10.3.3 Categorical and Schematic Organization

The use of categories or schemas to organize to-be-remembered information is often advocated as a mnemonic in textbooks (i.e., Solso, 2001; Matlin, 2005). A category organization involves organizing information in a taxonomic hierarchy whereby abstract category labels are used to organize subordinate exemplars. As an example, consider an angler who wishes to remember a list of items to needed for a fishing trip. The angler must remember the following items: rod and reel, motor key, filet knife, landing net, battery for boat, and plastic bags for storage of fish filets. These items could be organized into three separate categories, each of which subsumes two items. The battery and key would be subsumed under the category label boat items, the rod and reel and landing net would be subsumed under fishing tackle, and the knife and bags would be subsumed under fish-cleaning supplies. With this type of organization, one would need only to remember the category labels, which should cue the specific items to be remembered. As such, the organization of the to-be-remembered items should reduce cognitive load, and with this type of application, the intrusion of categorically related associates would not be necessarily problematic.

A schematic organization involves organizing to-be-remembered information such that spatial relations among items are maintained (Nakamura et al., 1992). Using our fishing-trip example, the needed items could be organized according to where they are to be placed in a boat. For example, the angler might note that the key and battery are in the stern of the boat, the fish-cleaning supplies in the main hatch, and the rod and reel and landing net in the bow of the boat. Thus, the stern, hatch, and bow of the boat would serve to organize and cue to-be-remembered items.

Empirical research using college-age adults (Nakamura et al., 1992) has demonstrated that information organized by taxonomic category and information organized into scene schemas is better recalled than unorganized information. Other research also using college-age adults (Khan and Paivio, 1988) has demonstrated that category organization and script-schema organization leads to equivalent levels of recall. However, it should be noted that categorical and schematic organization is unlikely to enhance recall in young children (Yoshimura et al., 1971).

### 2.10.4 Summary of Mnemonics and Mnemonic Processes

The mnemonics discussed in this chapter represent simple applications of well-established mnemonic processes. All of the mnemonics designed to enhance memory for lists included a procedure designed to enhance the organization of the to-be-remembered information. Moreover, the most effective of these mnemonics involve a combination of organization and at least one form of elaboration (see **Table 1** for a summary). The sole mnemonic discussed here that did not emphasize organization (the keyword method) was designed to enhance memory for paired associates rather than lists and thus would incur fewer benefits from organization. Nonetheless, even this method imposes some degree of organization on to-be-remembered information via the use of interactive mental imagery.

The importance of a combination of organization and elaboration to mnemonic effectiveness is attested by research that has shown that memory is enhanced by procedures that combine relational and item-specific processing (Einstein and Hunt, 1980; Hunt and Einstein, 1981). Relational processing refers to the processing of fundamental similarities among to-be-remembered items. Thus, relational processing is, in essence, organizational processing. Moreover,

**Table 1** Mnemonic Effectiveness as a Function of Processes Involved

| *Mnemonic* | *Organization* | *Elaboration* | *Imagery* | *Effectiveness* |
|---|---|---|---|---|
| Method of Loci | Yes | Yes | Yes | High |
| Peg-Word Method | Yes | Yes | Yes | High |
| Keyword Method | No | Yes | Yes | High |
| Acronyms (without imagery) | Yes | No | No | Low |
| Acronyms (with imagery) | Yes | No | Yes | Limited |
| Linking by Story | Yes | Yes | No | High |
| Category Organization | Yes | No | No | Limited |
| Schema Organization | Yes | No | No | Limited |

Note: Imagery has both organizational and elaborative properties.

relational processing is believed to enhance memory by specifying a common context in which all to-be-remembered items are embedded. On the other hand, item-specific processing – the processing of unique characteristics of individual items – can be induced by elaboration. Thus, by specifying both a common context and uniquely identifying characteristics of individual items, a combination of relational and item-specific information should enhance the discriminability of list items in memory (Hunt and McDaniel, 1993; Hunt, 2006).

Applied to mnemonics, research on relational and item-specific processing suggests that any mnemonic technique that involves a combination of organization and elaboration should facilitate memory. However, a mnemonic that emphasizes only organization or only elaboration is unlikely to result in strong memorial benefits. In support of the latter claim, the use of acronyms may be an ineffective mnemonic because it mainly emphasizes organizational processing with little emphasis on elaboration. As such, acronyms may serve to link to-be-remembered items together, but, without elaboration, individual items are not particularly discriminable in memory. However, the simple addition of elaboration (i.e., mental imagery) to compliment the already existing process of organization significantly increases mnemonic effectiveness of an acronym (Wilding et al., 1986). Similarly, research investigating the mnemonic effectiveness of bizarre imagery as a method of elaboration has found that, in the absence of an organizational scheme, bizarre imagery is no more effective than using common imagery when only one form of elaboration (bizarre or common) is used during learning (Wollen and Cox, 1981; McDaniel and Einstein, 1986). However, if bizarre elaboration is complemented by an organizational scheme (i.e., the method of loci and the peg-word method), the result is a successful mnemonic. Thus, it is likely that the exact nature of the organization and elaboration comprising a mnemonic is far less important than the requirement that some form of both organization and elaboration is used.

## 2.10.5 Practical Issues

A major issue in the application of mnemonic techniques is whether the main components of a given mnemonic should be provided to or generated by the learner. Although basic research (e.g., Bowbrow and Bower, 1969; Slamecka and Graf, 1978) supports the notion that generation enhances memory, the application of this finding within the context of mnemonic research is not without qualification. In terms of simple mnemonic processes (e.g., mental imagery), research (Jamieson and Schimpf, 1980; Ironsmith and Lutz, 1996; Kuo and Hooper, 2004) indicates that self-generated elaboration is more effective than elaboration that is provided. However, provided elaboration can be more effective than learner-generated elaboration if it is in the context of a mnemonic that is difficult to use (Patton et al., 1991) or if it is to be used with learning-impaired populations (Swanson et al., 1988; Canellopoulou and Richardson, 1998).

A more general issue related to self-versus-other generation is whether self-generated mnemonic strategies are more effective than mnemonics devised by others. If, as we have argued, a few basic cognitive processes can account for the effectiveness of formal mnemonics, then one may be inclined to abandon formal mnemonics in favor of self-generated applications of mnemonic processes. This sentiment is reflected in the results of a study by Park et al. (1990), which suggests that memory researchers and other psychologists are more likely to both use and recommend the use of general mnemonic processes (e.g., organization and elaboration) than formal mnemonics.

Although spontaneous use of formal mnemonics is infrequent (Intons-Peterson and Fournier, 1986; Soler and Ruiz, 1996), this does not mean that self-generated mnemonics are more useful. For example, Wang and Thomas (2000) examined the effectiveness of the method of loci, the peg-word method, self-generated organizational and imagery mnemonics, and rote rehearsal in determining serial recall. They found self-generated strategies to be least effective when recall was tested immediately, but as effective as formal mnemonics after a 48-h delay. Similarly, research with elderly participants (Derwinger et al., 2003, 2005) has indicated only minimal advantages of self-generated strategies compared to other-generated strategies even after training. Apparently, the benefits of generation and ease of use associated with self-generated mnemonics is offset by the effort involved with devising a personal strategy.

Taking into consideration research examining self-generated versus other-generated elaboration and, more generally, self- versus other-generated strategies, the most important point seems to be that mnemonics are quite flexible. That is, as long as an appropriate combination of cognitive processes is involved, a mnemonic can be effective regardless of whether it is fully self-generated or other-generated or whether it contains self- or other-generated components. Thus, the decision to use a self-generated or other-generated mnemonic may simply boil down to personal preference. As noted previously by Bellezza (1996), individual differences may play a large role in determining the effectiveness of any mnemonic. Considering that research also indicates that the effectiveness of a mnemonic depends on the demands of the learning situation (Roediger, 1980; Herrmann, 1987), it is likely that there is no single best mnemonic for a given person or even a given situation. As such, the best approach to improving memory across a variety of situations may be to have an assortment of mnemonic techniques at one's disposal.

## 2.10.6 Conclusions

Although a variety of strategies for enhancing memory have been offered throughout history, the most effective mnemonics involve some combination of organization and elaboration. Thus, it is likely that the specific means of encouraging organization and elaboration are less important than the requirement that both processes utilized. Similarly, when a mnemonic emphasizes both organization and elaboration, it can be effective regardless of whether it is devised by or provided to the learner. However, the appropriateness of any given mnemonic will be determined by characteristics of both the learner and the learning situation.

## References


Anderson JR (1983) *The Architecture of Cognition*. Cambridge, MA: Harvard University Press.

Anderson JR (1995) *Cognitive Psychology and Its Implications,* 4th ed.New York: Freeman.

Anderson DC and Buyer LS (1994) Is imagery a functional component of the ''bizarre imagery'' phenomenon? *Am. J. Psychol.* 107: 207–222.

Angier B (1956) *How to Stay Alive in the Woods*. New York: Black Dog and Leventhal.

Atkinson RC and Raugh MR (1975) An application of the mnemonic keyword method to the acquisition of a Russian vocabulary. *J. Exp. Psychol. Hum. Learn. Mem.* 1: 126–133.

Baddeley A (1990) *Human Memory: Theory and Practice*. London: Allyn & Bacon.

Beaton AA, Gruneberg MM, Hyde C, Shufflebottom A, and Sykes RN (2005) Facilitation of receptive and productive foreign vocabulary learning using the keyword method: The role of image quality. *Memory* 13: 458–471.

Bellezza FS (1981) Mnemonic devices: Classification, characteristics, and criteria. *Rev. Educ. Res.* 51: 247–275.

Bellezza FS (1986) A mnemonic based on arranging words on visual patterns. *J. Ed. Psychol.* 78: 217–224.

Bellezza FS (1996) Mnemonic methods to enhance storage and retrieval. In: Bjork EL and Bjork RA (eds.) *Memory*, pp. 345–380. San Diego, CA: Academic Press.

Bellezza FS, Six LS, and Phillips DS (1992) A mnemonic for remembering long strings of digits. *Bull. Psychon. Soc.* 30: 271–274.

Boltwood CE and Blick KA (1970) The delineation and application of three mnemonic techniques. *Psychon. Sci.* 20: 339–341.

Bousefield WA (1953) The occurrence of clustering in recall of randomly arranged associates. *J. Gen. Psychol.* 49: 229–240.

Bowbrow SA and Bower GH (1969) Comprehension and recall of sentences. *J. Exp. Psychol.* 80: 455–461.

Bower GH (1970) Imagery as a relational organizer in associative memory. *J. Verb. Learn. Verb. Behav.* 9: 529–533.

Bower GH and Clark MC (1969) Narrative stories as mediators for serial learning. *Psychon. Sci.* 14: 181–182.

Bower GH, Clark MC, Lesgold AM, and Winzenz D (1969) Hierarchical retrieval schemes in recall of categorized word lists. *J. Verb. Learn. Verb. Behav.* 8: 323–343.

Brigham FJ and Brigham MM (1998) Using mnemonic keywords in general music classes: Music history meets cognitive psychology. *J. Res. Dev.* 31: 205–213.

Broadbent DE, Cooper PJ, and Broadbent MH (1978) A comparison of hierarchical matrix retrieval schemes in recall. *J. Exp. Psychol. Hum. Learn. Mem.* 4: 486–497.

Brooks JO, Friedman L, Pearman AM, Gray C, and Yesavage JA (1999) Mnemonic training in older adults: Effects of age, length of training, and type of cognitive pretraining. *Int. Psychogeriatr.* 11: 75–84.

Bugelski BR (1968) Images as mediators in one-trial paired-associate learning: II. Self-timing in successive lists: *J. Exp. Psychol.* 77: 328–334.

Bugelski BR, Kidd E, and Segmen J (1968) Image as a mediator in one-trial paired-associate learning. *J. Exp. Psychol.* 76: 69–73.

Campos A, Amor A, and Gonzalez MA (2004) The importance of the keyword-generation method in keyword mnemonics. *Exp. Psychol.* 51: 125–131.

Canellopoulou M and Richardson JTE (1998) The role of executive function in imagery mnemonics: Evidence from multiple sclerosis. *Neuropsychologia* 36: 1181–1188.

Carlson L, Zimmer JW, and Glover JA (1981) First-letter mnemonics: DAM (don't aid memory). *J. Gen. Psychol.* 104: 287–292.

Carney RN and Levin JR (1991) Mnemonic facilitation of artists and their paintings: Effects of familiarity and correspondence. *Contemp. Educ. Psychol.* 16: 154–170.

Carruthers M (1990) *The Book of Memory: A Study of Medieval Culture*. New York: Cambridge University Press.

Christen F and Bjork RA (1976) *On updating the loci in the method of loci.* Paper presented at the 17th Annual Meeting of the Psychonomic Society, St. Louis, MO.

Collins AM and Loftus EF (1975) A spreading-activation theory of semantic processing. *Psychol. Rev.* 82: 407–429.

Cornoldi C, Cavedon A, De Beni R, and Pra Baldi A (1988) The influence of the nature of material and of mental operations on the occurrence of the bizarreness effect. *Q. J. Exp. Psychol.* 40: 73–85.

Cornoldi C and de Beni R (1991) Memory for discourse: Loci mnemonics and the oral presentation effect. *Appl. Cogn. Psychol.* 5: 511–518.

Craik FIM. (1979) Levels of processing: Overview and closing comments. In: Cermak LS and Craik FIM (eds.) *Levels of*

*Processing in Human Memory*, pp. 447–461. Hillsdale, NJ: Erlbaum.
Craik FIM and Tulving E (1975) Depth of processing and the retention of words in episodic memory. *J. Exp. Psychol. Gen.* 104: 268–294.
Cundus MM, Marshall KJ, and Miller SR (1986) Effects of the keyword mnemonic strategy on vocabulary acquisition and maintenance by learning disabled children. *J. Learn. Disabil.* 19: 609–613.
de Beni R and Cornoldi C (1988) Does repeated use of loci create interference? *Percept. Mot. Skills* 67: 415–418.
Derwinger A, Neely AS, and Backman L (2005) Design your own memory strategies! Self-generated strategy training versus mnemonic training in old age: An 8-month follow-up. *Neuropsychol. Bull.* 15: 37–54.
Derwinger A, Neely AS, Persson M, Hill RD, and Backman L (2003) Remembering numbers in old age: Mnemonic training versus self-generated strategy training. *Aging, Neuropsychol. Cogn.* 10: 202–214.
Dretzke BJ (1993) Effects of pictorial mnemonic strategy usage on prose recall of young, middle-aged, and older adults. *Educ. Gerontol.* 19: 489–502.
Drevenstedt J and Bellezza FS (1993) Memory for self-generated narration in the elderly. *Psychol. Aging* 8: 187–196.
Einstein GO and Hunt RR (1980) Levels of processing and organization: Additive effects of individual-item and relational processing. *J. Exp. Psychol. Hum. Learn. Mem.* 6: 588–598.
Elliot JL and Gentile JR (1986) The efficacy of a mnemonic technique for learning disabled and nondisabled adolescents. *J. Learn. Disabil.* 19: 237–241.
Fentress J and Wickham C (1992) *Social memory*. Oxford: Blackwell.
Glidden LM (1983) Semantic processing can facilitate free recall in mildly retarded adolescents. *J. Exp. Child Psychol.* 36: 510–532.
Grey R (1730) *Memoria technica: A New Method of Artificial Memory*. London: Charles King.
Groninger LD (1971) Mnemonic imagery and forgetting. *Psychon. Sci.* 23: 161–163.
Gruneberg MM (1973) The role of memorization techniques in finals examination preparation: A study of psychology students. *Educ. Res.* 15: 134–139.
Herrmann DJ (1987) Task appropriateness of mnemonic techniques. *Percept. Mot. Skills* 64: 171–178.
Herrmann DJ, Geisler FV, and Atkinson RC (1973) The serial position function for lists learned by a narrative-story mnemonic. *Bull. Psychon. Soc.* 2: 377–378.
Hill RD, Allen C, and McWhorter P (1991) Stories as a mnemonic aid for older learners. *Psychol. Aging* 6: 484–486.
Hunt RR (2006) The concept of distinctiveness in memory research. In: Hunt RR and Worthen JB (eds.) *Distinctiveness and Memory*, pp. 3–25. New York: Oxford University Press.
Hunt RR and Einstein GO (1981) Relational and item-specific processing in memory. *J. Verb. Learn. Verb. Behav.* 20: 497–514.
Hunt RR and McDaniel MA (1993) The enigma of organization and distinctiveness. *J. Mem. Lang.* 32: 421–445.
Hunt RR and Smith RE (1996) Accessing the particular from the general: The power of distinctiveness in the context of organization. *Mem. Cognit.* 24: 217–225.
Intons-Peterson MJ (1992) Components of auditory imagery. In: Reisberg D (ed.) *Auditory Imagery*, pp. 45–71. Hillsdale, NJ: Erlbaum.
Intons-Peterson MJ and Fournier J (1986) External and internal memory aids: When and how often do we use them? *J. Exp. Psychol. Gen.* 115: 267–280.
Ironsmith M and Lutz J (1996) The effects of bizarreness and self-generation on mnemonic imagery. *J. Ment. Imag.* 20: 113–126.
Jamieson DG and Schimpf MG (1980) Self-generated images are more effective mnemonics. *J. Ment. Imag.* 4: 25–33.
Jenkins JJ and Russell WA (1952) Associative clustering during recall. *J. Abnorm. Soc. Psychol.* 47: 818–821.
Johnson RB (1970) Images as mediators in free recall. *J. Exp. Psychol.* 84: 523–526.
Khan M and Paivio A (1988) Memory for schematic and categorical information: A replication and extension of Rabinowitz and Mandler (1983). *J. Exp. Psychol. Learn. Mem. Cogn.* 14: 558–561.
Kibler JL and Blick KA (1972) Evaluation of experimenter-supplied and subject-originated first-letter mnemonics in a free-recall task. *Psychol. Rep.* 30: 307–313.
Kolers PA (1979) A pattern analyzing basis of recognition. In: Cermak LS and Craik FIM (eds.) *Levels of Processing in Human Memory*, pp. 363–384. Hillsdale, NJ: Erlbaum.
Kosslyn SM, Seger C, Pani JR, and Hillger LA (1990) When is imagery used in everyday life? A diary study. *J. Ment. Imag.* 14: 131–152.
Kovar SK and Van Pelt C (1991) Using first-letter mnemonic to improve basketball set-shot. *Percept. Mot. Skills* 72: 1383–1390.
Krinsky R and Krinsky SG (1996) Pegword mnemonic instruction: Retrieval times and long-term memory performance among fifth-grade children. *Contemp. Educ. Psychol.* 21: 193–207.
Kuo MLA and Hooper S (2004) The effects of visual and verbal coding mnemonics on learning Chinese characters in computer-based instruction. *Educ. Tech. Res. Develop.* 52: 23–38.
Levin JR, Levin ME, Glasman LD, and Nordwall MB (1992) Mnemonic vocabulary instruction: Additional effectiveness evidence. *Contemp. Educ. Psychol.* 17: 156–174.
Lockhart RS, Craik FIM., and Jacoby LL (1976) Depth of processing, recognition, and recall: Some aspects of a general memory system. In: Brown J (ed.) *Recall and recognition*, pp. 75–102. London: Wiley.
Lorayne H (1990) *Super Memory—Super Student: How to Raise Your Grades in 30 Days*. Boston: Little Brown.
Lorayne H (1998) *The Complete Guide to Memory Mastery: Organizing and Developing the Power of your Mind*. Hollywood, FL: Fell's.
Lorayne H and Lucas J (1974) *The Memory Book*. New York: Ballantine.
Luria AR (1968) *The Mind of a Mnemonist*. New York: Avon.
Mandler G (1967) Organization in memory. In: Spence KW and Spence JT (eds.) *The Psychology of Learning and Motivation,* Vol. 1, pp. 327–372. New York: Academic Press.
Massen C and Vaterrodt-Plunnecke B (2006) The role of proactive interference in mnemonic techniques. *Memory* 14: 189–196.
Mastropieri MA, Scruggs TE, and Fulk BM (1990) Teaching abstract vocabulary with the keyword method: Effects on recall and comprehension. *J. Learn. Disabil.* 23: 92–96.
Matlin MW (2005) *Cognition*, 6th ed. Orlando, FL: Harcourt.
May JE and Clayton KN (1973) Imaginal processes during the attempt to recall names. *J. Verb. Learn. Verb. Behav.* 12: 683–688.
McDaniel MA and Einstein GO (1986) Bizarreness as an effective memory aid: The importance of distinctiveness. *J. Exp. Psychol. Learn. Mem. Cogn.* 12: 54–65.
McDaniel MA and Pressley M (1984) Putting the keyword method in context. *J. Ed. Psychol.* 76: 598–609.
McDaniel MA, Pressley M, and Dunay PK (1987) Long-term retention of vocabulary after keyword and context learning. *J. Ed. Psychol.* 79: 87–89.

McKinlay WW (1992) Achieving generalization in memory training. *Brain Inj.* 6: 107–108.
Moe A and de Beni R (2005) Stressing the efficacy of the loci method: Oral presentation and the subject-generation of the loci pathway with expository passages. *Appl. Cogn. Psychol.* 19: 95–106.
Morris PE and Reid RL (1970) The repeated use of mnemonic imagery. *Psychon. Sci.* 20: 337–338.
Nakamura GV, Kleiber BA, and Kim K (1992) Categories, propositional representations, and schemas: Test of a structural hypothesis. *Am. J. Psychol.* 105: 575–590.
Nelson DL (1979) Remembering pictures and words: Appearance, significance, and name. In: Cermak LS and Craik FIM (eds.) *Levels of Processing in Human Memory*, pp. 45–76. Hillsdale, NJ: Erlbaum.
Nelson DL and Archer CS (1972) The first-letter mnemonic. *J. Ed. Psychol.* 63: 482–486.
Paivio A (1969) Mental imagery in associative learning and memory. *Psychol. Rev.* 76: 241–263.
Paivio A, Smythe PC, and Yuille JC (1968) Imagery versus meaningfulness of nouns in paired-associate learning. *Can. J. Psychol.* 22: 427–441.
Park DC, Smith AD, and Cavanaugh JC (1990) Metamemories of memory researchers. *Mem. Cognit.* 18: 321–327.
Patton GWR, D'Agaro WR, and Gaudette MD (1991) The effect of subject-generated and experimenter-supplied code words on the phonetic mnemonic system. *Appl. Cogn. Psychol.* 5: 135–148.
Perewiznyk EK and Blick KA (1978) First-letter mnemonics and serial retention. *Psychol. Rep.* 43: 442.
Pinkofsky HB (1997) Mnemonics for DSM-IV personality disorders. *Psychiatr. Serv.* 48: 1197–1198.
Pinkofsky HB and Reeves RR (1998) Mnemonics for substance-related disorders. *Gen. Hosp. Psychiatry* 20: 368–370.
Pressley M (1981) Use of a mnemonic technique to teach young children foreign language vocabulary. *Contemp. Educ. Psychol.* 6: 110–116.
Pressley M (1982) Mnemonic versus nonmnemonic vocabulary-learning strategies: Additional comparisons. *J. Ed. Psychol.* 74: 693–707.
Pressley M, Levin JR, and Miller GE (1981) The keyword method and children's learning of foreign vocabulary with abstract meanings. *Can. J. Psychol.* 35: 283–287.
Pressley M, McDaniel MA, Turnure JE, Wood E, and Ahmad M (1987) Generation and precision of elaboration: Effects on intentional and incidental learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 13: 291–300.
Raaijmakers JG and Shiffrin RM (1981) SAM: Search of associative memory. *Psychol. Rev.* 88: 93–134.
Raugh MR and Atkinson RC (1975) A mnemonic method for learning a second-language vocabulary. *J. Ed. Psychol.* 67: 1–16.
Reddy BG and Bellezza FS (1986) Interference between mnemonic and categorical organization in memory. *Bull. Psychon. Soc.* 24: 169–171.
Richardson JTE (1978) Reported mediators and individual differences in mental imagery. *Mem. Cognit.* 6: 376–378.
Richardson JTE (1995) The efficacy of imagery mnemonics in memory remediation. *Neuropsychologia* 33: 1345–1357.
Roediger HL (1980) The effectiveness of four mnemonics in ordering recall. *J. Exp. Psychol. Hum. Learn. Mem.* 6: 558–567.
Rogers TB, Kuiper NA, and Kirker WS (1977) Self reference and the encoding of personal information. *J. Pers. Soc. Psychol.* 35: 677–688.
Ross J and Lawrence KA (1968) Some observations on memory artifice. *Psychon. Sci.* 13: 107–108.
Rubin DC (1995) *Memory in Oral Traditions: The Cognitive Psychology of Epic, Ballads, and Counting-Out Rhymes*. New York: Oxford University Press.
Rubin DC and Wallace WT (1989) Rhyme and reason: Analyses of dual retrieval cues. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 698–709.
Rummel N, Levin JR, and Woodward MM (2003) Do pictorial mnemonic text-learning aids give students something worth writing about? *J. Ed. Psychol.* 95: 327–334.
Short DD, Workman EA, Morse JH, and Turner RL (1992) Mnemonics for eight DSM-III-R disorders. *Hosp. Comm. Psychiat.* 43: 643–644.
Slamecka NJ and Graf P (1978) The generation effect: Delineation of a phenomenon. *J. Exp. Psychol. Hum. Learn. Mem.* 4: 592–604.
Smith EE, Shoben EJ, and Rips LJ (1974) Structure and process in semantic memory: A featural model for semantic decisions. *Psychol. Rev.* 81: 214–241.
Soler MJ and Ruiz JC (1996) The spontaneous use of memory aids at different educational levels. *Appl. Cogn. Psychol.* 10: 41–51.
Solso RL (2001) *Cognitive Psychology*, 6th ed. Boston: Allyn & Bacon.
Stalder DR (2005) Learning and motivational benefits of acronym use in introductory psychology. *Teaching Psychol.* 32: 222–228.
Swanson HL, Overholser JD, and Cooney JB (1988) The effects of self-generated visual mnemonics on adult learning disabled readers' word recall. *Learn. Disabil. Res.* 4: 26–35.
Sweeney CA and Bellezza FS (1982) Use of keyword mnemonics in learning English vocabulary. *Hum. Learn.* 1: 155–163.
Tess DE, Hutchinson RL, Treloar JH, and Jenkins CM (1999) Bizarre imagery and distinctiveness: Implications for the classroom. *J. Ment. Imag.* 23: 153–170.
Thomas MH and Wang AY (1996) Learning by the keyword mnemonic: Looking for long-term benefits. *J. Exp. Psychol. Appl.* 2: 330–342.
Troutt-Ervin ED (1990) Application of keyword mnemonics to learning terminology in the college classroom. *J. Exp. Educ.* 59: 31–41.
Tulving E (1962) Subjective organization in free recall of ''unrelated'' words. *Psychol. Rev.* 69: 344–354.
Tulving E (1983) *Elements of Episodic Memory*. Oxford: Oxford University Press.
Van Hell JG and Mahn AC (1997) Keyword mnemonics versus rote rehearsal: Learning concrete and abstract foreign words by experienced and inexperienced learners. *Lang. Learn.* 47: 507–546.
Veit DT, Scruggs TE, and Mastropieri MA (1986) Extended mnemonic instruction with learning disabled students. *J. Ed. Psychol.* 78: 300–308.
Waite CJ, Blick KA, and Boltwood CE (1971) Prior usage of the first-letter technique. *Psychol. Rep.* 29: 630.
Wallace WT and Rubin DC (1991) Characteristics and constraints in ballads and their effects on memory. *Discourse Processes* 14: 181–202.
Wang AY and Thomas MH (1992) The effect of imagery-based mnemonics on long-term retention of Chinese characters. *Lang. Learn.* 42: 359–376.
Wang AY and Thomas MH (1995) The effect of keywords on long-term retention: Help or hindrance? *J. Ed. Psychol.* 87: 468–475.
Wang AY and Thomas MH (2000) Looking for long-term mnemonic effects on serial recall: The legacy of Simonides. *Am. J. Psychol.* 113: 331–340.
Wang AY, Thomas MH, Inzana CM, and Primicerio LJ (1993) Long-term retention under conditions of intentional learning and the keyword mnemonic. *Bull. Psychon. Soc.* 31: 545–547.
Wang AY, Thomas MH, and Ouellette JA (1992) The keyword mnemonic and retention of second language vocabulary. *J. Ed. Psychol.* 84: 520–528.

Weir D and Richman CL (1996) Subject-generated bizarreness: Imagery or semantic processing. *Am. J. Psychol.* 109: 173–185.

Wilding J, Rashid W, Gilmore D, and Valentine E (1986) A comparison of two mnemonic methods in learning medical information. *Hum. Learn. J. Prac. Res. Appl.* 5: 211–217.

Wilson BA (1995) Management and remediation of memory problems in brain-injured adults. In: Baddeley AD, Wilson BA, and Watts FN (eds.) *Handbook of Memory Disorders*, pp. 451–479. Chichester: Wiley.

Wollen KA and Cox SD (1981) Sentence cuing and the effectiveness of bizarre imagery. *Bull. Psychon. Soc.* 5: 386–392.

Wollen KA, Weber A, and Lowry DH (1972) Bizarreness versus interaction of mental images as determinants of learning. *Cognit. Psychol.* 3: 518–523.

Wood G (1967) Mnemonic systems in recall. *J. Ed. Psychol.,* 58: 1–27.

Wood G and Bolt M (1970) Type of instruction, abstractness and mnemonic system. *Psychon. Sci.* 21: 91–92.

Wood LE and Pratt JD (1987) Pegword mnemonic as an aid to memory in the elderly: A comparison of four age groups. *Educ. Gerontol.* 13: 325–339.

Worthen JB (1997) Resiliency of bizarreness effects under varying conditions of verbal and imaginal elaboration and list composition. *J. Ment. Imag.* 21: 167–194.

Worthen JB (2006) Resolution of discrepant memory strengths: An explanation of the effects of bizarreness on memory. In: Hunt RR and Worthen JB (eds.) *Distinctiveness and memory*, pp. 133–156. New York: Oxford University Press.

Worthen JB and Marshall PH (1996) Intralist and extralist distinctiveness and the bizarreness effect: The importance of contrast. *Am. J. Psychol.* 109: 239–263.

Yarmey AD (1984) Bizarreness effects in mental imagery. In: Sheikh AA (ed.) *International Review of Mental Imagery,* vol. 1, pp. 57–76. New York: Huffman Sciences Press.

Yates FA (1966) *The Art of Memory*. London: Routledge & Kegan Paul.

Yesavage JA, Rose TL, and Bower GH (1983) Interactive imagery and affective judgments improve face-name learning in the elderly. *J. Gerontol.* 38: 197–203.

Yoshimura EK, Moely BE, and Shapiro SI (1971) The influence of age and presentation order upon children's free recall and learning to learn. *Psychon. Sci.* 23: 261–263.

# 2.11 Human Spatial Memory and Navigation

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## 2.11.1 Introduction

Effective navigation abilities are crucial for the survival of almost every living mobile species. They are essential, for instance, for finding the way back to a previously discovered source of food or water, for safely returning home after a sudden change of weather, and for not getting lost in a complex environment such as a cave. For most modern humans, effective navigation skills have become less critical for daily survival, but many common activities, such as getting to work and back home, are nevertheless still characterized by the need to navigate successfully between places.

Successful navigation relies on two capabilities. First, the organism needs to be able to construct enduring internal representations of the locations and identities of significant objects or landmarks in the environment. Second, the organism needs to be able to stay oriented with respect to these represented elements. As the organism moves, the spatial relations between the organism and the elements in the environment constantly change. To remain oriented and to avoid getting lost, spatial updating processes need to be invoked to compensate for those changes.

The goal of this chapter is to review empirical and theoretical advancements in the scientific understanding of human spatial memory and navigation. Our focus is on memories acquired from direct experience, such as vision and locomotion, and on spaces sufficiently large to afford movement, such as translation and rotation, although we also refer to some findings obtained from studies investigating memories of tabletop-sized environments. We are especially interested in the ways memories of familiar environments are used to guide locomotion, reorientation, and wayfinding. Our decision to focus on these topics should not be interpreted to imply that we believe that other types of spatial memories, such as those obtained from language or indirect sources such as maps, are not important or not interesting. Indeed, for modern humans, navigation based on maps and written works, such as guidebooks, may be at least as important as navigation using one's sense of direction and knowledge of the relations between visible and invisible parts of an environment. Because of space limitations, we were forced to trade breadth against depth of coverage and opted to explore a smaller set of topics in detail, at the expense of several topics equal in importance to those covered here (for reviews of greater scope, see Golledge, 1999; Montello, 2005).

This chapter is divided into nine primary sections. We begin by discussing the elemental types of spatial knowledge: object identity, routes, environmental shape, and survey knowledge. In the second section, we investigate classical and current theories of the acquisition of spatial knowledge. The third section discusses properties of spatial knowledge, such as its hierarchical structure and orientation dependence. In the fourth section, we examine the concept of spatial reference systems and the nature of the spatial reference systems used in spatial memory and navigation. We then turn our attention to the processes and representations that underlie the abilities to guide locomotion and to avoid getting lost. In the sixth section of the chapter, we review contemporary theories of spatial memory and navigation, with an eye for similarities. The seventh section examines the development of spatial memory and navigational capabilities. The eighth and penultimate section looks at the brain networks underlying spatial memory abilities. We close the chapter with a summary and prospectus for future research on human spatial memory and navigation.

## 2.11.2 Types of Spatial Knowledge

### 2.11.2.1 Object Identity

The most elemental type of spatial knowledge may be knowledge of the identities and appearances of objects or environmental features (a hill, an intersection of paths, etc.). We use the term object identity to refer to this type of knowledge, recognizing that many entities in an environment that are important for navigation may not be objects in the narrow sense of the term (e.g., path intersection, saddle between two hills). This type of knowledge is sometimes referred to as landmark knowledge (e.g., Siegel and White, 1975), although landmark knowledge is a special case of object knowledge. People know the identities of many objects in their environments that may not serve as landmarks. Landmarks are objects of special significance to spatial memory and navigation (e.g., Couclelis et al., 1987): They are used to indicate the locations of other objects (e.g., the restaurant is in the basement of the Maxwell House Hotel); they may be the goals of navigation (e.g., I am going to Ryman Auditorium); they mark the locations of changes of direction (e.g., turn right at the Gaylord Entertainment Center); and they are used to maintain course (e.g., you will pass Tootsies Orchid Lounge on your right). According to Siegel and White's (1975) theory of the acquisition of spatial knowledge (discussed in the section titled 'Microgenesis of spatial knowledge'), landmark knowledge is the first to be acquired and is the building block of other types of spatial knowledge.

### 2.11.2.2 Route Knowledge

Route knowledge consists of knowledge of sequences of landmarks and associated decisions and actions. Actions specify the steps needed to get to the next landmark on the route (e.g., turn right at the post office and drive three blocks to the Laundromat). According to Siegel and White's theory, route knowledge does not represent distance, temporal duration, or turning angles early in acquisition. Such metric properties are acquired gradually with experience in an environment.

### 2.11.2.3 Environmental Shape

The importance of knowledge of environmental shape was discovered relatively recently. Cheng (1986) found that when rats searched for the known location of food in rectangular enclosures they often committed rotational errors in which they searched the correct location and the incorrect location differing from the correct one by 180° of rotation. For instance, if the correct location was in one of the corners, the rotational error would be the corner diagonally opposite to the correct corner. These errors occurred even when nongeometric featural cues, such as visual or tactile patterns, were available that would allow the rat to distinguish the correct location from the rotational error. Similar findings have been observed in many species, including humans (for a review, see Cheng and Newcombe, 2005). There is ample evidence that people are sensitive to environmental geometry when they learn a new environment (e.g., Shelton and McNamara, 2001;

Schmidt and Lee, 2006) and when they reorient and navigate (e.g., Sandstrom et al., 1998; Hartley et al., 2004; Ruddle and Péruch, 2004).

### 2.11.2.4 Survey Knowledge

Knowledge of the overall configuration of an environment, including knowledge of Euclidean (straight-line) distances and of interpoint directions, defined in a common reference system, makes up survey knowledge. A key feature of survey knowledge is that the spatial relations between locations can be retrieved or inferred even if the organism has never traveled between the locations. Survey knowledge of an environment is often referred to as a cognitive map (a term coined by Tolman, 1948) and likened to physical maps, although such language and parallels imply isomorphisms between the mental and the physical that do not exit. Survey knowledge is considered to be the most sophisticated type of knowledge obtained about an environment (e.g., Siegel and White, 1975). Behaviors taken to be the signature of survey knowledge include the abilities to create efficient routes (e.g., taking shortcuts), to point directly to unseen locations, and to estimate Euclidean distances.

## 2.11.3 Microgenesis of Spatial Knowledge

The process of the acquisition of spatial knowledge of a new environment has been referred to as microgenesis. The classical theory of the microgenesis of spatial knowledge was proposed by Siegel and White (1975) and it remains the dominant theory in the field (Montello, 1998). According to this theory, the identities and appearances of landmarks are learned first, followed by routes between landmarks. Route knowledge is primarily nonmetric early in acquisition, consisting of the order of landmarks and the appropriate actions to be taken at each one in the sequence. Through experience, route knowledge can acquire metric, or at least approximately metric, properties, such as distance, temporal duration, and turning angles. The most sophisticated form of spatial knowledge is survey knowledge, which is assumed to be derived from accumulated route knowledge (e.g., Thorndyke and Hayes-Roth, 1982).

Although this theoretical framework has been enormously influential, it has not received a great deal of empirical support (for reviews, see Montello, 1998; Ishikawa and Montello, 2006). The limitations of the classical theory are apparent in the findings of a recent study published by Ishikawa and Montello (2006). Participants in this experiment were passively transported by automobile along two routes in a private residential area. The routes passed around and over many hills, and afforded few views of distant landmarks. Learning took place over 10 days (once a week for 10 weeks); on the fourth and subsequent days, participants were transported along a connecting route between the two routes and encouraged to learn the spatial relation between them. Participants' knowledge of the routes and their interrelations was tested using landmark recall, direction estimates, route and Euclidean distance estimates, and map drawing.

Performance was above chance on all tasks after the first session, and near perfect on some, such as landmark sequence recall and route distance estimation. Direction estimates and more difficult distance estimates (e.g., Euclidean estimates within the more complex route) were only moderately accurate and improved modestly over the course of learning. However, substantial individual differences were observed. Some participants performed very well after only one or two sessions and maintained high performance levels on all tasks across all sessions. Another subgroup of participants performed poorly throughout the experiment and showed very little learning on the more challenging tasks, even after 12–14 h of exposure to the routes. Only about half of the participants improved monotonically over the course of learning, and those gains were not large.

These findings largely validate the theoretical distinction between route and survey knowledge, as tasks sensitive to route information, such as landmark sequence recall and route distance estimation, produced similar patterns of results, and tasks sensitive to the layout of the routes, such as Euclidean distance estimation, direction estimates, and map drawing, produced results similar to each other but different from the route tasks. However, these results contradict several key predictions of the classical theory. Landmark knowledge and route knowledge were acquired almost simultaneously. Route knowledge seemed to contain some quantitative information from the very beginning. Even at the earliest stages of learning, participants had some knowledge of the spatial layout of the routes. Finally, although some participants gained more accurate knowledge of the layouts of the routes over the course of learning, few of them could be characterized as having gained accurate survey knowledge of the environments (see also, Gärling et al., 1981; Golledge, 1993).

The evidence on spatial knowledge acquisition is most consistent with Montello's theoretical framework (Montello, 1998; Ishikawa and Montello, 2006). According to this theory, the process of acquiring knowledge of the spatial structure of large-scale environments consists of incremental accumulation of metric knowledge, instead of stage-wise transitions between qualitatively distinct types of spatial knowledge. Spatial knowledge is never limited solely to nonmetric information. This theory emphasizes the importance of knowledge integration – combining knowledge about separately learned places into more complex hierarchically organized representations – in spatial knowledge acquisition. However, even this theoretical framework does not predict or explain the large individual differences observed by Ishikawa and Montello.

## 2.11.4 Nature of Spatial Knowledge

### 2.11.4.1 Fragmented

Spatial knowledge is typically fragmented, in the sense that it consists of a patchwork of detailed knowledge of some areas and only sparse knowledge of other, possibly neighboring, areas (e.g., Lynch, 1960; Appleyard, 1970). Survey knowledge never has the property of being of uniformly high fidelity for all familiar areas.

### 2.11.4.2 Distorted

A second key property of spatial knowledge is that memories of spatial relations, such as distances, angles, and orientation, often differ from the physical values in systematic and predictable ways (e.g., Tversky, 1992, 2000). As discussed in several sections of this chapter, such distortions have played a prominent role in the development of theories of spatial memory.

Estimates of Euclidean distances are greater when locations are separated by a barrier or boundary (e.g., Kosslyn et al., 1974; Newcombe and Liben, 1982; McNamara, 1986) and tend to increase with the clutter between the locations (e.g., Thorndyke, 1981). Boundary effects occur even when the boundaries are subjective (e.g., McNamara et al., 1989; Carbon and Leder, 2005). Estimates of route distance increase with the number of turns (e.g., Byrne, 1979; Sadalla and Magel, 1980) and the number of intersections (e.g., Sadalla and Staplin, 1980). Distance estimates are also asymmetric under certain circumstances (e.g., Sadalla et al., 1980; McNamara and Diwadkar, 1997; Newcombe et al., 1999). In particular, distances from less salient locations or objects to more salient locations or objects (i.e., landmarks or reference points) are underestimated relative to the reverse. Angles of intersection between roads are remembered as being closer to 90° than they are in reality (e.g., Byrne, 1979; Tversky, 1981; Moar and Bower, 1983; Sadalla and Montello, 1989). Disparate regions of space, such as states or continents, are remembered as being aligned with each other, and individual regions of space are remembered as being oriented with canonical reference axes (e.g., Stevens and Coupe, 1978; Tversky, 1981). For instance, people believe that North America and South America are vertically aligned, even though the east coast of the U.S. is roughly aligned with the west coast of South America, and that the Bay Area of Northern California is oriented north-south, even though it actually is oriented along a north-west/south-east axis (Tversky, 1981). These biases produce systematic errors in judgments of the relative directions between objects and cities.

### 2.11.4.3 Hierarchical

There is strong evidence that memories of the locations of objects in the environment are organized categorically and hierarchically, such that a region of space may be represented as a whole, containing other regions and locations, and as a part, contained in larger regions. One indication that spatial memories are hierarchical is that judgments of the spatial relations between cities or objects are affected by the spatial relations between superordinate regions (e.g., Stevens and Coupe, 1978; Tversky, 1981; McNamara, 1986). For instance, in Stevens and Coupe's (1978) experiments, Reno was judged to be northeast of San Diego, even though it is actually northwest. According to hierarchical models of spatial memory, this error occurs, at least in part, because people represent Reno in Nevada, San Diego in California, and Nevada east of California. These spatial relations imply that Reno should be east of San Diego. Other evidence consistent with the hierarchical representation of space includes the effects of boundaries on distance estimations (cited previously), the effects of region membership on judgments of orientation (e.g., Wilton, 1979; Maki, 1981) and proximity (e.g., Allen, 1981), and errors in estimates of latitude, bearing, and distance at global scales (e.g., Friedman and Brown, 2000; Friedman et al., 2002; Friedman and Montello, 2006).

Even stronger evidence for hierarchical representations can found in studies in which task performance is shown to depend on the structure of explicit hierarchical models of spatial memory (e.g., Hirtle and Jonides, 1985; Huttenlocher et al., 1991; McNamara, 1986; McNamara et al., 1989). For instance, McNamara et al. (1989, Experiment 1) required subjects to learn the locations of objects in a large room; the objects were unrelated, and there were no physical or perceptual boundaries in the space. After learning, subjects were asked to recall all of the objects several times, to estimate distances between pairs of objects, and to take part in an item recognition test in which the measure of interest was spatial priming (e.g., McNamara et al., 1984). The latent hierarchical structure in each subject's recall protocols was modeled with the ordered-tree algorithm (e.g., Reitman and Rueter, 1980). An example is illustrated in **Figure 1**. Distance estimations and spatial priming were conditionalized on whether pairs of objects were in the same or different subtrees (e.g., ruler–coin vs. envelope–truck), controlling for Euclidean distance. Different subtrees were assumed to correspond to different subjective regions of space. Subjects underestimated distances between pairs of objects in the same subjective region relative to pairs of objects in different subjective regions, and spatial priming was greater between pairs in the same subjective region than between pairs in different subjective regions. Additional analyses showed that spatial priming increased with the depth at which object pairs were clustered (e.g., ruler–coin vs. ruler–pen vs. ruler–screw). These findings provide strong evidence that spatial memories are organized hierarchically, even when the layout lacks explicit perceptual organization.

The hierarchical structure of spatial memory affects navigation behavior, at least in virtual environments. Wiener and Mallot (2003) found that people minimized the number of region boundaries

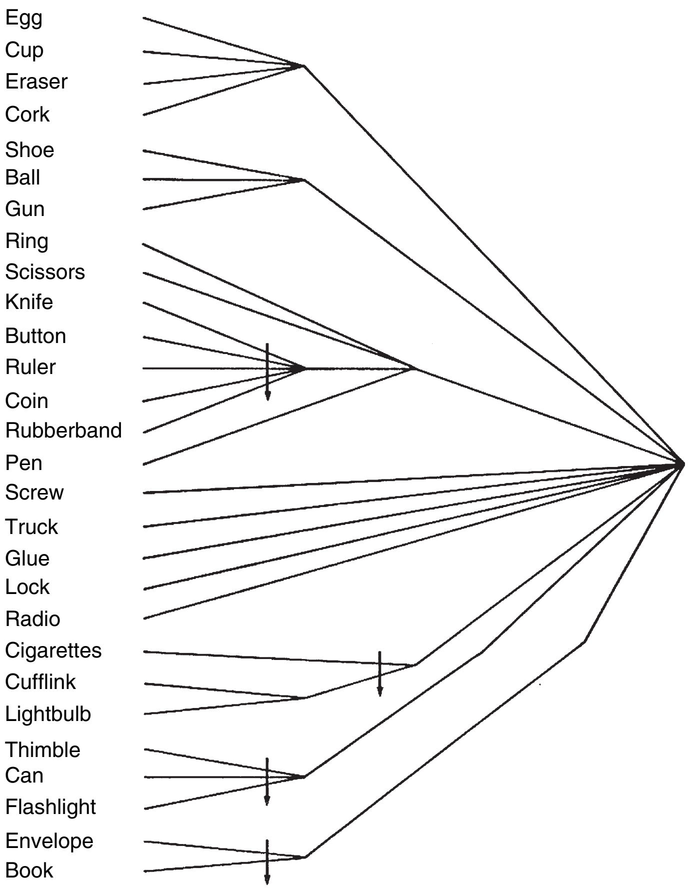


**Figure 1** Ordered tree generated from recall protocols for a single participant. Reprinted with permission from McNamara TP, Hardy JK, and Hirtle SC (1989) Subjective hierarchies in spatial memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 15(2): 211–227.

crossed when navigating to a goal location and that they tended to choose paths that permitted the quickest access to the region containing the goal location. Wiener et al. (2004) showed further that subjects learned environments faster and searched more efficiently when environments were divided into regions than when they were not. This improvement was on the order of a factor of 2. Their results also revealed that navigation strategies seemed to depend on the alignment of the dominant reference directions between different levels of the hierarchical mental representation (see also, Werner and Long, 2003; Werner and Schindler, 2004). (The concept of spatial reference directions and axes will be explored in detail in the section 'Spatial reference systems'.)

### 2.11.4.4 Orientation Dependent

It is well documented that long-term spatial memory is orientation-dependent (see McNamara, 2003, for a review). People recall and recognize interobject spatial relations more efficiently from some perspectives than from others. These privileged perspectives are usually aligned with (parallel or orthogonal to) experienced points of view (e.g., Shelton and McNamara, 2001) but also may be aligned with salient intrinsic axes of the array of objects (e.g., Mou and McNamara, 2002; Mou et al., 2007). Typical results are illustrated in **Figure 2**. There is evidence that spatial memories also may be viewpoint-dependent (e.g., Easton and Sholl, 1995; Waller, 2006; Valiquette and McNamara, 2007). Behaviorally this means that performance is better when the test perspective matches the location of the observer at the time of learning in addition to his or her orientation.

Orientation-independent performance has been observed in several published investigations of spatial memory (e.g., Evans and Pezdek, 1980; Presson and Hazelrigg, 1984; Presson et al., 1989; Sholl and Nolin, 1997, Experiments 3 and 4; Richardson et al., 1999, real-walk condition). McNamara (2003) discusses possible limitations of these studies in some detail. One important feature of those studies (with the exception of Evans and Pezdek's) is that only two orientation conditions were compared: The perspective parallel to and in the same direction as the learning view (0°) and the perspective differing by 180°. This fact may be important because task performance for the imagined heading of 180° is often much better than performance for other novel headings, and can be nearly as good as that for the learning view (e.g., Hintzman et al., 1981; Mou and McNamara, 2002). The cause of this effect is not known, but people may sometimes represent, at least partially, the spatial structure of the layout in the direction opposite to the learning view (Mou et al., 2004). It is also possible that people are able to capitalize, under certain conditions, on the fact that arrays of objects may have high self-similarity under rotations of 180° (e.g., Vetter et al., 1994). Investigations of the orientation dependence of spatial memories are at a distinct disadvantage if only the learning view and its opposite are compared.

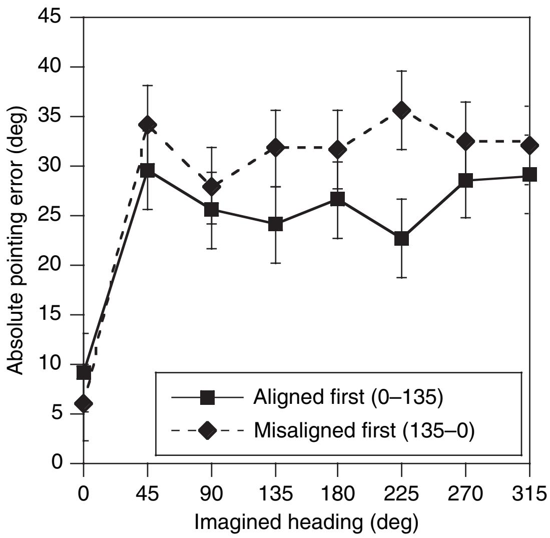


**Figure 2** Results of Shelton and McNamara's (2001) third experiment. Participants learned the layout of seven objects in a room from two points of view (counterbalanced across participants): One view (0°) was aligned with salient environmental reference frames (e.g., walls of the room, square mat on which the objects were placed), and the other (135°) was misaligned with these features. Absolute pointing error in subsequent judgments of relative direction is plotted as a function of imagined heading, separately for the two learning-order groups. Results show that participants represented the layout using a single reference direction parallel to the aligned view and demonstrate the importance of environmental frames of reference in the selection of reference directions in memory. From Shelton AL and McNamara TP (2001) Systems of spatial reference in human memory. *Cogn. Psychol.* 43(4): 274–310.

## 2.11.5 Spatial Reference Systems

Spatial reference systems are essential for the specification of location and orientation in space. The location of Murfreesboro, Tennessee, for example, can be specified by describing its position with respect to the boundaries of the state (e.g., Murfreesboro is in the center of Tennessee), by providing coordinates of latitude and longitude on the surface of the earth (e.g., Murfreesboro is located at 35°55′ N and 86°22′ W), or by describing its position relative to an observer (e.g., Murfreesboro is 31 miles to the first author's left as he writes this paragraph). People represent in memory the spatial properties of many familiar environments. Just as spatial reference systems are required to specify the locations of objects in physical space, so too spatial reference systems must be used by human memory systems to represent the remembered locations of objects in the environment.

A spatial reference system is a relational system consisting of reference objects, located objects, and the spatial relations that may exist among them (e.g., Rock, 1973, 1992; Talmy, 1983). The reference objects may be any objects whose positions are known or established as a standard and may include the observer, other objects in the environment, abstract coordinate axes, and so forth. Note that, according to this definition, a reference frame consisting of orthogonal axes is just one of many types of spatial reference systems. Many schemes for classifying spatial reference systems have been proposed (e.g., Hart and Moore, 1973; Paillard, 1991; Pani and Dupree, 1994; Levinson, 1996; Tversky et al., 1999). For the purposes of understanding the use of spatial memories in navigation and other actions in space, it is useful to distinguish egocentric and environmental reference systems (e.g., Klatzky, 1998). In this chapter, we consider environmental and allocentric reference systems to be equivalent.

Egocentric reference systems specify location and orientation with respect to the organism, and include eye-, head-, and body-based coordinate systems (e.g., Andersen et al., 1997). Returning to the previous example, the description of Murfreesboro's location relative the first author of this chapter uses an egocentric reference system.

Environmental reference systems define spatial relations with respect to elements of the environment, such as the perceived direction of gravity, the sun's azimuth, landmarks, or the walls of a room (e.g., Wehner et al., 1996). Abstract reference systems, such as coordinates of latitude and longitude, also qualify as environmental reference systems. An important subcategory of environmental reference systems are intrinsic reference systems. Intrinsic reference systems can be centered on an object (e.g., Rock, 1973; Marr, 1982). In such cases, the objects usually have inherent facets, such as natural fronts, backs, tops or bottoms, that can be used to define reference axes. The human body is a paradigmatic example. Intrinsic reference systems can also be defined by features of a collection of objects (e.g., Tversky, 1981; Mou and McNamara, 2002). The rows and columns formed by chairs in a classroom constitute an intrinsic reference system. Intrinsic reference systems also may be defined by less explicit perceptual organization, such as an axis of bilateral symmetry or the mutual alignment of several objects (e.g., Mou et al., 2007). An example is illustrated in **Figure 3**.

The primate brain represents the locations of objects in space using egocentric and environmental reference systems (e.g., Andersen et al., 1997; Snyder et al., 1998; Matsumura et al., 1999), and human navigation depends on both egocentric and environmental representations of the environment. Actions such as walking through doorways and other apertures, staying on paths, and avoiding obstacles require the computation of precise self-to-object spatial relations to guide locomotion (e.g., Rieser and Pick, 2006). But planning a route to a distant goal, and maintaining a sense of orientation in large-scale environments, would seem to require enduring representations of the locations of objects relative to other objects (e.g., Loomis and Beall, 1998). Contemporary theories of human spatial memory and navigation specify roles for both egocentric and environmental representations of space, and will be reviewed in detail in the section titled 'Models of spatial memory and navigation'.

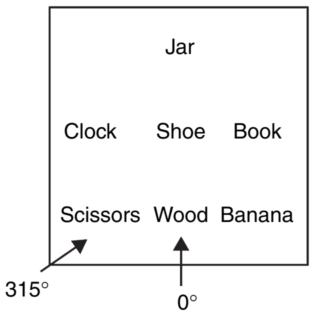


**Figure 3** Layout used by Mou and McNamara (2002). Zero degrees is an axis of bilateral symmetry, increasing the salience of that axis and therefore the probability that it will be selected as a reference direction, even if participants study the layout from a different direction such as 315°. Reprinted with permission from Mou W and McNamara TP (2002) Intrinsic frames of reference in spatial memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 28(1): 162–170.

The concept of spatial reference systems proves useful for accounting for two key properties of spatial knowledge. The orientation dependence of spatial memories indicates that the spatial layout of an environment is mentally represented using a dominant reference direction (e.g., Shelton and McNamara, 2001). Interobject spatial relations that are specified with respect to this reference direction can be retrieved, whereas other spatial relations must be inferred (e.g., Klatzky, 1998), introducing costs in latency and errors. The preferred directions in judgments of relative direction, for example, correspond to intrinsic directions in the layout that are experienced or are highlighted by instructions or layout geometry (e.g., Shelton and McNamara, 2001; Mou and McNamara, 2002; Mou et al., 2007). These preferred directions correspond to the dominant reference directions. A simple model of this form that accounts for orientation dependence in judgments of relative direction is illustrated in **Figure 4**.

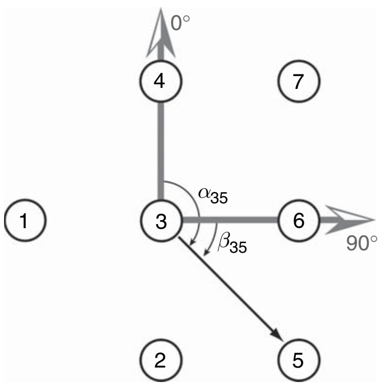


**Figure 4** Schematic depiction of an orientation dependent model of enduring spatial memory. Circles symbolize the represented objects. Interobject spatial relations are symbolized by vectors; for simplicity, only the spatial relation between objects 3 and 5 is represented. Grey arrows symbolize reference directions in the representation. The angular relation from object 3 to object 5 is represented with respect to the 0° ($\alpha_{35}$) and the 90° ($\beta_{35}$) reference directions. Because the direction from object 3 to object 5 relative to 0° is explicitly represented in memory, a task such as ''Imagine you are standing at 3 and facing 4. Point to 5'' is relatively easy, because that direction can be retrieved from memory. A task such as ''Imagine you are standing at 3 and facing 7. Point to 5'' in contrast, is relatively difficult, because the spatial relation between objects 3 and 5 is not represented relative to 45° and, therefore, must be inferred, which produces measurable performance costs. An important feature of the model is that it uses an environmental reference system, yet produces orientation-dependent performance.

The second key property explained by spatial reference systems is the hierarchical structure of spatial knowledge. This property may result from the use of spatial reference systems at multiple scales (e.g., Poucet, 1993). A region of space that can be viewed in its entirety from a single vantage point with minimal locomotion (vista scale as defined by Montello and Golledge, 1999) may be represented in a locally defined spatial reference system. Spatial reference systems used in neighboring regions of space may be interrelated in higher-order reference systems in which the local reference systems serve as elements. For instance, the spatial layout of each of the rooms in a house may be specified in a spatial reference system unique to the room. These spatial reference systems may serve as elements in a higher-order reference system defining the spatial relations among the rooms.

Reference systems within the same level and between levels of the hierarchy need not use common reference directions; that is, conceptual north in one region may or may not correspond to conceptual north in a neighboring region. The acquisition of skills attributed to the possession of survey knowledge, such as pointing accurately to unseen targets, may occur when the reference directions in such locally defined reference systems become integrated in such a way that all are aligned (Montello and Pick, 1993). Werner and colleagues (Werner and Long, 2003; Werner and Schindler, 2004) have shown that misalignment of reference directions in such a reference system hierarchy impairs way-finding performance and produces less accurate knowledge of interobject directions. Experiments reported by Wang and Brockmole (2003a) provide evidence that people maintain orientation with respect to a single reference system as they navigate. They had participants walk from a room in a building on a college campus to the outdoors and then back inside to the room. When oriented with respect to the room, participants lost track of their orientation with respect to the campus, and when oriented with respect to the campus, they lost track of their orientation with respect to the room (see also, Wang and Brockmole, 2003b).

## 2.11.6 Navigation and Spatial Updating

The processes and representations used in human navigation can be divided into three categories. Navigation that depends solely on the organism's history of self-movement is referred to as path integration, or dead reckoning. By integrating velocity or double integrating acceleration with respect to time, an organism can estimate its displacement from a starting location (e.g., Gallistel, 1990). Cues to velocity or acceleration can be internal (e.g., proprioception, efference copy, vestibular cues) or external (e.g., optic or acoustic flow); however, to the extent that external cues are used, path integration is limited to situations in which external cues do not provide information about the organism's position in the environment (Philbeck et al., 2001). Wayfinding (or piloting), by contrast, refers to navigation that depends jointly on an enduring external or internal spatial representation (a map or cognitive map, respectively) and the observation of objects whose locations are specified in the spatial representation (e.g., Gallistel, 1990). The key feature of wayfinding is that the organism uses a representation of the layout of an environment and its perception of objects in that environment to find or orient with respect to objects that cannot be observed. Both path integration and wayfinding may require the organism to pass through apertures (e.g., doorways), follow paths, avoid obstacles and hazards, and so forth. This form of navigation has been referred to as steering (e.g., Rieser and Pick, 2006). Steering requires an organism to guide locomotion in relation to the perceived locations of objects but does not rely on an enduring external or internal spatial representation of the environment.

In general, as an organism locomotes through an environment, it must keep track of its location with respect to objects in the immediate environment and to unseen portions of the environment, to avoid obstacles, to remain oriented, and to navigate to distant goals (Loomis and Beall, 1998; Montello, 2005). These processes are referred to as spatial updating. Experimental research on human navigation has typically been aimed at trying to uncover the mental representations and processes used in spatial updating more broadly, and with the exception of work on path integration, does not divide neatly into categories corresponding to the three types of navigation.

Path integration is often investigated with triangle completion, or return-to-home tasks. An illustrative study was reported by Klatzky et al. (1990). Blindfolded participants were guided along paths of varying complexity and then required to walk back to the starting points. The paths consisted of one to three linear segments, separated by turns. The dependent variables were the angular turn participants made toward the origin and the distance they walked toward it. Participants' errors on both measures were low for the one-leg path and increased with the increasing number of segments. In general, path integration in humans is only moderately accurate and becomes less so as path complexity increases (e.g., Loomis et al., 1993, 1999; Cornell and Heth, 2004; Foo et al., 2005).

Nonvisual spatial updating has also been investigated in tasks that require the participant to keep track of multiple objects simultaneously. For example, Rieser et al. (1986) asked participants to study the locations of five objects in a room and then point to them while blindfolded. Participants were subsequently escorted to a novel position from which they had to point to the objects again. Locomotion resulted in small, nonsignificant updating costs relative to baseline (e.g., Rieser, 1989).

The results from these and similar paradigms suggest that humans are capable of relatively efficient updating when they move without vision, provided that the movement trajectory is not very complex. The increase in error for more prolonged movement is compatible with the assumption of an updating process that does not operate with perfect accuracy and accumulates error over the course of movement.

Spatial updating necessarily involves computations that compensate for the changes in observer–environment relations caused by locomotion. A number of studies have been conducted to identify which of the cues that are normally associated with physical locomotion are sufficient for efficient spatial updating. Purely imaginary locomotion typically produces inefficient spatial updating (e.g., Rieser et al., 1986; Rieser, 1989; but see, Wraga, 2003). Optic flow appears to be insufficient for efficient spatial updating (e.g., Chance et al., 1998; Klatzky et al., 1998; Péruch et al., 1997; but see Kearns et al., 2002; Riecke et al., 2002). A prerequisite for efficient updating seems to be that the person's physical position changes (Ruddle and Lessels, 2006). Whether this position change is accomplished through passive transport, which primarily provides vestibular cues, or through active movement, which provides additional proprioceptive and efferent cues, does not matter in many circumstances (e.g., Wang and Simons, 1999; Wraga et al., 2004). There is, however, evidence that those additional cues become beneficial when the movement trajectory is more complex (e.g., Sholl, 1989; Yardley and Higgins, 1998; Waller et al., 2004).

Evidence indicates that spatial updating during physical locomotion has two properties commonly attributed to automatic processes. First, it seems to require little attentional effort (e.g., Amorim et al., 1997; Wang, 2004). Second, the changes in observer–environment spatial relations produced by physical locomotion are difficult to ignore (e.g., Farrell and Robertson, 1998; Farrell and Thomson, 1998; Wang and Simons, 1999; May and Klatzky, 2000; Waller et al., 2002). For example, in Farrell and Robertson's experiment, participants were required to rotate to a novel orientation, but point to objects as if they were still facing their initial orientation. Performance was as poor in this ignore-rotation condition as in the imagined rotation condition, indicating that participants were unable to voluntarily refrain from updating.

Another important property of automatic processes is their relative insensitivity to processing load. The evidence on the capacity limits of spatial updating is mixed. Results of at least one study indicate that spatial updating deteriorates in accuracy as the number of objects increases (Wang et al., 2006), whereas findings from other studies indicate that spatial updating is capacity-free (Rieser and Rider, 1991; Hodgson and Waller, 2006). This pattern of results has led some researchers to distinguish two forms of updating, one that occurs on-line and relies on working memory and another that occurs off-line and relies on long-term memory (e.g., Amorim et al., 1997; Cornell and Greidanus, 2006; Hodgson and Waller, 2006). This distinction is embodied in several theories of spatial memory and navigation (discussed in the section titled 'Models of spatial memory and navigation').

A common interpretation of the advantage in spatial updating produced by physical locomotion in the absence of vision (e.g., walking while blindfolded) relative to imagined locomotion is that body-based information facilitates the transformations needed to update observer–environment spatial relations (e.g., Rieser, 1989; Chance et al., 1998; Farrell and Robertson, 1998). This facilitation may result from the transfer of learned relationships between action and perception to relationships between action and representations (e.g., Rieser et al., 1995; Pick et al., 1999; Rieser, 1999; Rieser and Pick, 2006). The idea is that people learn the consistent covariations between their actions and the resulting changes in the appearance of the environment. This tight coupling of action and perception is proposed to be the basis for a coupling of action and representation. When a person moves without vision, he or she can use the learned covariation between biomechanical cues from locomotion and the changes in environmental flow to update the self-to-object relations at a representational level. It is argued that, by utilizing this learned covariation during locomotion, people can access the changing self-to-object relations directly rather than having to go through effortful cognitive computations.

An alternate account posits that the difficulty of updating after imagined movements results from interference that is caused by a conflict between the awareness of one's physical position in an environment and the discrepant position one has to adopt in imagination (e.g., May, 1996, 2004). May (2004) has proposed that interference arises from conflicts between object location codes at the sensorimotor level, which are specified relative to the physical position, and object location codes at the cognitive level, which are specified relative to the imagined position. Consistent with this hypothesis, pointing to objects from imagined facing directions is worse when people are oriented than when they are disoriented (e.g., May, 1996; Waller et al., 2002). The interference hypothesis is also supported by the finding that performance in both imagined rotations and imagined translations degrades monotonically as a function of object-direction disparity (May, 2004), which is defined as the magnitude of the difference between (1) the direction of the to-be-retrieved object relative to the imagined position and (2) the direction of the to-be-retrieved object relative to the physical position. To account for the finding that imagined rotations are more difficult than imagined translations (e.g., Rieser, 1989; Presson and Montello, 1994), even when object direction disparity is equated, May (2004) proposed a second source of interference that only applies to imagined rotations. This second source of interference, referred to as head-direction disparity, reflects conflicts that arise from having to specify an object direction relative to an imagined heading that is different from one's physical heading (e.g., Mou et al., 2004).

May (2004) has also shown that providing participants with additional time between the presentation of the to-be-imagined position and the presentation of the target object improved overall performance, but did not mitigate the effect of object-direction disparity in either imagined rotations or imagined translations. This finding indicates that the spatial transformations required for effective spatial updating cannot be performed efficiently in working memory, even if they are somehow facilitated by physical locomotion.

In summary, extant findings indicate that spatial updating during imagined locomotion is difficult in part because knowledge of object locations relative to the actual position interferes with knowledge of object locations relative to the imagined position.

But in addition, imagined spatial updating does not benefit from facilitative transformations provided by physical locomotion.

## 2.11.7 Models of Spatial Memory and Navigation

Cognitive models of spatial memory and navigation attempt to explain how the spatial structure of an environment is represented in memory and how memories of familiar environments are used to guide navigation. All of the models employ both egocentric and environmental representations of space, and although there are important differences between models in the nature of those representations and in the ways they are used to maintain orientation and guide navigation, the models are fundamentally quite similar.

These models include an egocentric system that computes and represents self-to-object spatial relations needed for spatially directed motor activity, such as walking, reaching, and grasping. In the models proposed by Burgess and colleagues (e.g., Burgess, 2002; Burgess et al., 2001; Byrne et al., 2007), Mou and colleagues (Mou et al., 2004, 2006) and Waller and Hodgson (2006), spatial relations represented in this system are transient and decay rapidly in the absence of perceptual support or deliberate rehearsal. In Sholl's model (Sholl and Nolin, 1997; Sholl, 2001; Holmes and Sholl, 2005) and in Wang and Spelke's model (2002), this system is dynamic but can represent more enduring egocentric self-to-object spatial relations. Recent evidence implicates the role of a transient egocentric system in spatial updating, but this evidence is far from definitive (Mou et al., 2006; Waller and Hodgson, 2006).

The second major system in all of the models is an environmental (allocentric) system. Wang and Spelke's model is perhaps the most unusual, in that the environmental system in this model only represents environmental shape. It is difficult to reconcile this aspect of the model with the abilities of people to judge interobject distances and directions using long-term memories of the layouts of environments. The other major difference among models, at least among those which specify the nature of the reference systems used in the environmental system, is whether the spatial reference system is orientation-dependent or -independent. Mou and McNamara argue that the environmental system uses an intrinsic reference system (as discussed in the section titled 'Spatial reference systems'). Sholl, in contrast, claims that an orientation-independent reference system is used, at least in well-learned environments. Sholl's model would seem to have difficulty accounting for the large body of evidence demonstrating orientation-dependent performance in spatial memory tasks, even for well-learned environments, as reviewed previously.

Finally, Wang and Spelke's model includes a third system in which the appearances of familiar landmarks and scenes are represented. These representations are viewpoint-dependent and can be conceived of as visual-spatial snapshots of the environment (e.g., Diwadkar and McNamara, 1997; Wang and Simons, 1999; Burgess et al., 2004). Valiquette and McNamara (2007) recently attempted to find evidence for such a system and to determine whether it could be distinguished from an environmental system. They asked participants to learn the locations of objects in a room from two points of view, one of which was aligned with salient environmental frames of reference (the mat on which the objects were placed and the walls of the room), and the other of which was misaligned with those same frames of reference (i.e., a view from the corner of the room). Participants then took part in judgments of relative direction (e.g., 'Imagine you are standing at the shoe, facing the lamp; point to the banana') and old–new scene recognition. Performance in judgments of relative direction was best for the imagined heading parallel to the aligned learning view and no better for the imagined heading parallel to the misaligned learning view than for unfamiliar headings. This pattern of orientation-dependent performance replicates previous findings (e.g., Shelton and McNamara, 2001; Valiquette et al., 2007). Performance in scene recognition, however, was equally good for the two familiar views and better for familiar than for novel views (see also Waller, 2006). These findings are consistent with a model in which interobject spatial relations are represented in an environmental system using intrinsic reference systems, as specified in Mou and McNamara's model, and visual memories of landmarks and scenes are stored in a viewpoint-dependent system, as specified in Wang and Spelke's model.

This viewpoint-dependent system may account for the effectiveness of the look-back strategy in wilderness navigation (e.g., Cornell et al., 1992). Routes often look quite different coming and going, leading to navigational errors on the return trip. The look-back strategy involves occasionally stopping and turning around to view one's route in the opposite direction while navigating in unfamiliar wilderness environments. These look-back views may be stored in the viewpoint-dependent system and support place recognition when returning.

Spatial updating in these models takes place at two levels. Self-to-object spatial relations are continuously and efficiently updated in the egocentric system as a navigator locomotes through an environment. This updating process supports steering and interactions with objects in the environment. At the same time, the navigator must update a representation of his or her position in the environment, to remain oriented and to locate distant goals. This updating process takes place in the environmental system. According to Mou and McNamara, navigators update their position with respect to the intrinsic reference system used to represent the spatial structure of the local environment. Sholl's model is the most explicit about the environmental updating process. In this model, the egocentric system is referred to as the self-reference system, and it codes self-to-object spatial relations in body-centered coordinates, using the body axes of front–back, right–left, and up–down (e.g., Franklin and Tversky, 1990; Bryant and Tversky, 1999). The engagement of the self-reference system with the physical environment determines the position of a representation of the self-reference system in the environmental system. As a person moves in the environment, the axes of the representational self-reference system are moved to the corresponding new position in the environmental system representation.

To a significant degree, these models primarily describe the perceptual-cognitive architecture of the human spatial memory and navigation system. For this reason, they have varying amounts to say about the various topics covered previously in this chapter. All are intimately concerned with object location, survey knowledge, spatial reference systems, and spatial updating. But none of these models has much to say about route knowledge, the microgenesis of spatial knowledge, or the nature of spatial knowledge (e.g., distortions). An important direction for future research will be to extend these models to account for a broader array of findings in the spatial memory and navigation literature.

## 2.11.8 The Developmental Foundations of Navigation

Decades of research have revealed a host of burgeoning spatial abilities during the first few years of life. These developments are most likely intimately coupled with changing motor abilities (for discussion, see Campos et al., 2000) and, toward the end of infancy, symbolic capabilities such as language. In this section, we focus on the development of rudimentary abilities necessary for navigation (for a recent and more comprehensive review, see Newcombe and Huttenlocher, 2006). Specifically, we discuss the development of two of the elemental types of spatial knowledge: object location (including landmarks) and environmental shape. Route and survey knowledge follow later in development (e.g., Allen et al., 1979) and most likely depend on these earlier abilities. In addition, we consider what children's responses in various situations reveal about early use of egocentric and environmental spatial frames of reference.

### 2.11.8.1 How Children Use Objects and Landmarks

In the first months of life, infants can locate objects through response learning, which involves learning the association between a bodily response (e.g., an eye movement or a reach) and a particular position in space. For example, an infant may learn that lying in her crib she can turn her head to the left to see a colorful toy. Response learning illustrates a very simplistic egocentric reference system – one that does not take self-movement into account. In order to locate objects after movement through space, infants must be capable of what Rieser (2000) has called dynamic spatial orientation, which requires awareness of one's changing orientation with respect to the world.

Early studies have suggested limitations on the infants' ability to keep track of an object's location during self-movement. Acredolo (1978) examined 6-, 11-, and 16-month-olds in the following task. Infants first learned that an auditory cue signaled an interesting event in one of two windows (either on the left side of the room or on the right side of the room for each infant). Infants were then carried on a semicircular path to the opposite side of the room. Only 16-month-olds looked toward the correct window when the cue sounded, whereas younger infants continued to look toward the egocentric side on which the event had occurred earlier. Similar results were obtained by Bremner and Bryant (1977), who found that 9-month-olds continued to search for an object on the egocentric side of a table after being moved to the opposite side of the table.

These initial studies seemed to suggest that sometime during the second year there is a transition from response learning (not taking movement into account) to spatial updating (taking movement into account). However, it is likely that even very young infants use spatial updating when simple forms of movement, such as rotation about the trunk or tilting with respect to gravity, are involved (e.g., Rieser, 1979; Landau and Spelke, 1988). Furthermore, Newcombe and Huttenlocher (2000) have argued that spatial development is most likely characterized by an increased weighting of relevant cues rather than by the appearance of wholly new abilities (for evidence in older children, see Hund and Spencer, 2003). As infants become more mobile and can perform more complex actions in larger environments, cues such as self-movement and landmarks become increasingly relevant.

Early studies have also examined infants' ability to use landmarks as direct cues to locating objects. A direct landmark is one that is either contiguous with or adjacent to some target, thus serving as a beacon for the target location. (Because no coding of distance or angular information is necessary, use of direct landmarks is technically associative rather than spatial in nature.) In contrast is an indirect landmark, which is distant enough from a target that both are not visually available at the same time; consequently, in order to use an indirect landmark a viewer must represent the spatial relations between it and the target location. Acredolo and Evans (1980) explored the landmark use of 6-, 9-, and 11-month-olds. The task was similar to that used by Acredolo (1978) in that infants were carried to the opposite side of the room before searching for an event in a left or right window. Nine- and 11-month-olds clearly benefited from the presence of a landmark that surrounded the correct window, whereas 6-month-olds did not. A consistent finding was that of Bremner (1978), who found that 9-month-olds who moved to the opposite side of the table were more likely to search on the correct side for an object if the left and right hiding places were noted by a black cover and a white cover. Such findings seemed to indicate that, before they are capable of spatial updating, infants are able to use direct landmarks to locate targets. Additionally, when landmarks are highly salient, even 6-month-olds sometimes use them in locating target objects or events (Rieser, 1979; Lew et al., 2004).

Toward late infancy, humans show evidence of using landmarks in the surrounding environment in complex ways. Newcombe et al. (1998) examined children between the ages of 16 and 36 months in a task that required them to locate a toy in a long rectangular sandbox. Success required distance coding (in the continuous space of the sandbox) rather than the categorical coding involved in many earlier studies (e.g., at the left or right window). The children searched either with a circular curtain surrounding them (thus, with no indirect landmarks visible) or without the curtain (thus, in full view of surrounding landmarks in the room). After children watched an experimenter hide a toy in the sand, they moved to the opposite side of the box to perform the search. Children older than 22 months were more accurate when indirect landmarks were visible, whereas the youngest children performed the same whether the landmarks were visible or not. These data suggested that toward the end of infancy children begin to use indirect landmarks to guide navigation (see also DeLoache and Brown, 1983; Bushnell et al., 1995).

While Newcombe et al. (1998) argued that the indirect landmarks aided children's search, it is also possible that children were using the shape of the room (see discussion in section titled 'How children use environmental shape'). Consistent with this latter argument is a recent study by Nardini et al. (2006), who found that 3-year-olds were able to use the shape of the room during a search task that involved indirect landmarks, but not until 5 years did children seem to use the actual landmarks. In fact, there is recent evidence to indicate that young children do not represent landmarks in an environmental reference system.

In a series of experiments, Gouteux and Spelke (2001) examined preschoolers' ability to search for a target that was hidden inside one of several identical landmarks within a room. When landmarks were identical, the configuration (a triangle in some experiments and a rectangle in others) was the only available spatial information. The critical trials took place after children were disoriented within the search space. Across all experiments, children failed to use the configuration specified by the arrangement of landmarks. In contrast, when landmarks were differentiated, children were successful in locating the target. Gouteux and Spelke (2001) noted that the landmarks could have served as beacons for the target location rather than as cues to reorientation within the space.

Lee et al. (2006) explored this latter possibility. Four-year-olds searched for an object among three landmarks that formed an equilateral triangle – thus, the geometric information alone was uninformative; two of the landmarks were identical. As in Gouteux and Spelke's (2001) experiments, children were disoriented before beginning their search. Children successfully retrieved objects that were hidden at the distinctive landmark; however, when objects were hidden at one of the two identical landmarks, children searched at each of those two landmarks with equal frequency. Lee et al. (2006) argue that children can use landmarks as beacons for target locations, but do not use them to reorient to the locations of other landmarks (see also, MacDonald et al., 2004). These findings are consistent with researchers who have argued that humans keep track of discrete objects egocentrically (Wang and Spelke, 2000; Wang et al., 2006). Once these egocentric relations are disrupted, humans cannot use individual objects to reorient to the locations of other objects. The validity of this claim has been a matter of dispute in the adult literature (see discussion in section titled 'Models of spatial memory and navigation'). However, children at least do seem to have difficulties remembering the locations of objects with respect to other objects.

### 2.11.8.2 How Children Use Environmental Shape

When toddlers and older children see an object hidden in one corner of a rectangular space and then undergo a disorientation procedure, they search equally in the correct corner and in the geometrically equivalent corner (Hermer and Spelke, 1994; Learmonth et al., 2001, 2002; see for a discussion Cheng and Newcombe, 2005). Since there is no spatial information available other than the shape formed by the walls of the room, these data clearly demonstrate that, by the time they can walk, humans use the shape of extended surfaces to reorient when lost and to locate desired objects. Furthermore, children's use of geometric information in extended surfaces generalizes to situations in which they are translated outside of the space before searching (Lourenco et al., 2005) and to spaces that are not rectangular (Huttenlocher and Vasilyeva, 2003; Hupbach and Nadel, 2005). Finally, the knowledge of geometric shape must be stored in an environmental reference system, since the disorientation would have disrupted any self-to-surface representations. The shape of extended surfaces, in contrast to object location, seems readily represented in an environmental reference system early in development.

When geometric information is ambiguous, combining that information with other sources of information can be a powerful tool. One question is whether children can combine information about the shape of a room with featural information, unlike rats and other species, which cannot combine these two sources of information (see discussion in the section titled 'Environmental shape'). Hermer and Spelke (1994) examined 3- and 4-year-old children in the following task. Children watched as an object was hidden in a corner of a rectangular room, were disoriented, and then were allowed to search for the object. The researchers found that when one of the walls was blue, making the correct choice of corner unambiguous, young children did not search with greater frequency in the correct corner. Since adults have no difficulty combining the geometry of the room with landmark information, Hermer and Spelke (1996) hypothesized that humans use language capabilities to solve such a task, a hypothesis supported by Hermer-Vasquez et al. (2001). In this study, adults who performed a verbal shadowing task while searching for an object that was hidden in one of four corners were less likely to use relevant landmarks in the room.

There is some controversy over the claim that geometric shape of space cannot be used in combination with landmarks without the aid of language (Learmonth et al., 2001, 2002; Hupbach and Nadel, 2005; see for a discussion Cheng and Newcombe, 2005). However, there is a considerable amount of support for the claim that geometric information, at least in some situations, is processed independently from other spatial cues. One particularly important variable seems to be the size of the room (Learmonth et al., 2002). In spaces that afford only minimal locomotion, children are more likely to ignore featural information and rely solely on the shape of the room. The reasons for this finding, whether they relate to limited locomotion, the proximity of landmark information, or both, are not yet clear (see for discussion Newcombe and Huttenlocher, 2006).

## 2.11.9 Cognitive Neuroscience of Spatial Memory

Our goal in this section is to review some of the primary findings that have emerged from decades of research on the neural bases of spatial memory. Recently there has been a growing focus on understanding how egocentric and environmental reference systems operate in parallel and interact with each other. First we discuss how the hippocampal and parietal cortices subserve spatial memory. Next we turn to a discussion of the parahippocampal cortex, which has been the focus of recent growing interest in its role in navigation and its possible role in hippocampal–parietal interactions.

In now classic research with rats, O'Keefe and Dostrovsky (1971) demonstrated the existence of place cells in the hippocampus, which fire selectively based on the position in the environment that the animal occupies, independently of the animal's facing direction. O'Keefe and Nadel (1978) argued that these cells serve as the basis for an environmental spatial reference system, or the cognitive map. Ekstrom et al. (2003) have provided the first demonstration of place cells in the human hippocampus, confirming what was long hypothesized from several lines of research with humans. This literature has shown that the human hippocampus is involved in performance on a variety of spatial tasks (e.g., Maguire et al., 1997; Holdstock et al., 2000; Kesner and Hopkins, 2001; Stepankova et al., 2004). In particular, the hippocampus seems to be crucial for performance on spatial tasks that require learning the relations among external landmarks, i.e., tasks that cannot be solved using egocentric responding (Astur et al., 2002; Bohbot et al., 2004; Parslow et al., 2004; Shelton and Gabrieli, 2004).

Recently discovered grid cells in adjacent entorhinal cortex (Hafting et al., 2005) may serve a function complementary to place cells. Grid cells respond whenever the animal is in a position that coincides with a vertex in a grid of equilateral triangles that spans the surface of the environment. The grid is initially anchored to landmarks in the environment, although the cells continue to fire even in the dark. Thus, the cells may serve as the neural basis for an environmental reference system, in conjunction with the place cells, and also facilitate path integration within that environment.

In contrast to individuals who have endured damage to hippocampal regions, those with lesions to parietal regions sometimes exhibit severe difficulty navigating through immediate space, often failing to avoid obstacles (e.g., Stark et al., 1996). Such findings have led researchers to postulate that the parietal cortex is critically involved in action and, specifically, in representing self-to-surface relations (see for discussions Andersen et al., 1997; Colby and Goldberg, 1999).

Recently there has been a growing emphasis on how the parahippocampal cortex (PHC) serves spatial functioning. PHC is ideally situated for combining information from parietal and other temporal areas and also projects to entorhinal cortex, a primary input region for the hippocampus. As noted by Epstein:

> . . . the anatomical data suggest that a pathway from parietal cortex to parahippocampal cortex to the hippocampus may be critical for processing navigationally relevant spatial information. (Epstein, 2005: 971)

Neuroimaging studies have shown the PHC to be involved in a wide range of navigation tasks (e.g., Aguirre et al., 1996; Maguire et al., 1996; Mellet et al., 2000; Shelton and Gabrieli, 2002). In addition, humans who have endured damage to this area exhibit impairments in spatial tasks such as route learning and scene recognition (e.g., Bohbot et al., 1998; Aguirre and D'Esposito, 1999; Barrash et al., 2000; Luzzi et al., 2000; Epstein et al., 2001).

The posterior region of the PHC has been the focus of increasing interest due to its dedication to the perception of spatial scenes. In a functional magnetic resonance imaging (fMRI) investigation, Epstein and Kanwisher (1998) found that this area responds more to scenes than to houses, faces, or objects, even during passive viewing. Further experiments revealed that this area responds just as strongly to empty rooms as to scenes with multiple objects. Additionally, this region responds more to coherent scenes than to those in which the component parts are fractured and rearranged. Based on this set of findings, Epstein and Kanwisher called this region of cortex the parahippocampal place area (PPA). Both neuroimaging and lesion studies suggest that the PPA's role is one of encoding (Brewer et al., 1998; Epstein et al., 1999, 2001). Epstein et al. (2003) conducted a study indicating that the region processes geometric information in background elements, in particular. These researchers found that the PPA responds as much to changes in entire scenes as it does to changes in viewpoint of the same scene, suggesting that the PPA processes scene information in a viewpoint-dependent (egocentric) manner. However, there is evidence that over time the way the PPA processes particular scenes may become more viewpoint-independent (Epstein et al., 2005).

One notable finding that has contradicted studies on the PPA was that by Maguire et al. (1998). These researchers found activations of the right PHC when subjects navigated through and learned a series of rooms with salient objects in a virtual reality environment. However, they did not find any medial temporal involvement when participants performed the same task with a series of empty rooms distinguished from each other only by their different shapes. They hypothesized that the parahippocampal region is involved in object-location binding, not analysis of the geometry of the scene. Consistent with this view is the recent finding that monkeys with lesions to the PHC are impaired in the formation of object–place associations (Malkova and Mishkin, 2003; see also Parkinson et al., 1988) and the finding by Bohbot et al. (1998) that humans with lesions to the right PHC are impaired in a spatial task that requires memory for object locations. The contradictory findings may have to do with functional differentiation within the PHC, with the PPA serving a specialized purpose of geometrical analysis and other regions involved in binding object information to the geometry.

## 2.11.10 Summary and Prospectus

Learning a new environment typically begins by learning routes from place to place; even in large-scale outdoor environments, navigation usually takes advantage of trails of some kind. People quickly acquire knowledge of the identities of important objects, or landmarks, and the sequential order of landmarks on routes. Route knowledge has at least quasi-metric properties very early during acquisition. Humans and many other organisms seem to be very sensitive to the shape of the immediate environment and to depend on environmental shape to reorient. With extensive experience in an environment, people sometimes acquire knowledge of its overall layout, or survey knowledge. The acquisition of spatial knowledge is best characterized as the incremental accumulation of quantitative spatial relations. Spatial knowledge does not seem to be limited to qualitative, nonmetric information at any point during acquisition.

Humans represent the locations of objects in space using egocentric and environmental (i.e., allocentric) reference systems, and navigation almost certainly depends on both egocentric and environmental representations of the environment. There is evidence that the process of learning a new environment involves interpreting the spatial structure of that environment in terms of an environmental spatial reference system. Interobject spatial relations seem to be specified with respect to a small number of reference directions. This aspect of the mental representation produces one of its key properties, orientation dependence: interobject spatial relations can be utilized more efficiently from perspectives aligned with the dominant reference directions in memory. These reference directions are typically parallel to points of view experienced during learning, but also may be determined by instructions and by properties of the environment, such as the mutual alignment of several objects or geographical slant. The use of spatial reference systems at multiple scales may explain why spatial knowledge is hierarchically organized.

Effective navigation in a familiar environment depends on the abilities to avoid obstacles and stay on course, to use one's history of self-movement to keep track of one's position, and to use mental representations of the layout of the environment to estimate the positions of objects that cannot be observed. Collectively, these abilities – steering, path integration, and wayfinding, respectively – are referred to as spatial updating. A prerequisite for efficient updating seems to be that the navigator's position in space changes. Imagined spatial updating is difficult and error-prone. An important source of this inefficiency seems to be conflicts that are created by having to imagine a position in the environment that is different from one's physical position in that environment. Physical locomotion in the absence of vision mitigates this interference and also seems to benefit from body-based information, which facilitates the transformations needed to update observer–environment spatial relations. But even physical nonvisual updating breaks down with prolonged movement over complex trajectories.

Contemporary models of spatial memory and navigation specify roles for three types of spatial memories: Egocentric self-to-object spatial relations used for steering and path integration, viewpoint-dependent representations of landmarks and scenes used for place recognition, and environmental representations of object-to-object spatial relations used for wayfinding and some forms of path integration. There are differences among the models in the properties of each of these representational systems and in the manner in which they are used in navigation. For instance, in some models, the egocentric system computes and represents transient representations, whereas in other models, these representations are more enduring. In one model, the environmental system only represents the shape of the environment and is used for reorientation, whereas in the others, it represents object-to-object spatial relations and is used for virtually all locomotion in familiar environments. Despite these differences, however, the models are quite similar in terms of their overall architecture.

The development of these capabilities begins with simple forms of egocentric spatial coding, such as learning the association between a bodily response and a location in space, and of spatial updating, such as compensating for trunk rotation. During the second year of life, children begin to be able to use landmarks in more sophisticated ways and to update after complex movements, developments that are coincident with (and certainly related to) their increased mobility. By the time children can walk, they can use environmental shape, as defined, for example, by the shape of a room, to locate a desired object. This knowledge must be represented in an environmental frame of reference because it survives disorientation, which destroys self-to-object spatial relations. Toddlers appear to have difficulty under some conditions using featural cues or landmarks to find a desired object after having been disoriented. The ability to effectively use such cues does not develop until well into the school-age years.

Research on the neural basis of spatial memory and navigation in humans has isolated the hippocampus, the parietal cortex, and the parahippocampal cortex as especially important brain areas. The hippocampus seems to be critically involved in the formation of long-term representations of the spatial structure of the environment using environmental frames of reference. The parietal cortex is involved in representing the locations of objects in the egocentric reference systems needed for sensorimotor mappings and in coordinating these representations. The parahippocampal cortex is involved in navigation, and its posterior regions seem to play an important role in representing landmarks and scenes.

The scientific understanding of human spatial memory and navigation has advanced enormously since Tolman (1948) presaged the distinction between route and survey knowledge with his categorization of spatial memories into strip maps and comprehensive maps. Significant progress has been made in understanding the nature and acquisition of spatial memories, how remembered spatial relations are used to guide navigation, properties of spatial updating processes, the development of early navigational capabilities, and areas of the brain involved in spatial memory and navigation. But of course much remains to be discovered. Many important avenues of future research are indicated by the findings reviewed in this chapter. A few especially promising ones, to our minds, include the following.

There is abundant evidence of the hierarchical organization of enduring spatial memories, but the processes involved in the formation of such representations are not well understood. Of special interest are the mechanisms used to establish correspondences between representations that use different reference directions and the spatial updating processes used to switch from one hierarchical level to another. The relative importance of egocentric and environmental representations in various spatial tasks, their dynamical properties, and the processes by which egocentric representations in sensorimotor systems are transformed into environmental representations, and vice versa, are largely unknown. Much remains to be learned about how children come to represent spatial relations among landmarks in ways that effectively support navigation. Recent investigations of spatial updating in adults suggest that steering depends on a transient egocentric system, whereas wayfinding depends on an enduring environmental system. Relatively little is known about the nature and the development of these capabilities in children. Finally, research on the neural basis of human spatial memory and navigation has isolated a network encompassing, at minimum, the parietal cortex, the hippocampus, and the parahippocampal cortex. The nature of the representations in these areas and the interactions among them need to be explored in greater depth.

We look forward, with optimism, to seeing the empirical and theoretical fruits of these efforts to understand how people remember where they have been and how they find their way home.

## References


Acredolo LP (1978) Development of spatial orientation in infancy. *Dev. Psychol.* 14(3): 224–234.

Acredolo LP and Evans D (1980) Developmental changes in the effects of landmarks on infant spatial behavior. *Dev. Psychol.* 16(4): 312–318.

Aguirre GK and D'Esposito M (1999) Topographical disorientation: A synthesis and taxonomy. *Brain* 122(9): 1613–1628.

Aguirre GK, Detre JA, Alsop DC, and D'Esposito M (1996) The parahippocampus subserves topographical learning in man. *Cereb. Cortex* 6(6): 823–829.

Allen GL (1981) A developmental perspective on the effects of ‘‘subdividing’’ macrospatial experience. *J. Exp. Psychol. [Hum. Learn.]* 7(2): 120–132.

Allen GL, Kirasic KC, Siegel AW, and Herman JF (1979) Developmental issues in cognitive mapping: The selection and utilization of environmental landmarks. *Child Dev.* 50(4): 1062–1070.

Amorim MA, Glasauer S, Corpinot K, and Berthoz A (1997) Updating an object's orientation and location during nonvisual navigation: A comparison between two processing modes. *Percept. Psychophys.* 59(3): 404–418.

Andersen RA, Snyder LH, Bradley DC, and Xing J (1997) Multimodal representation of space in the posterior parietal cortex and its use in planning movements. *Annu. Rev. Neurosci.* 20, 303–330.

Appleyard D (1970) Styles and methods of structuring a city. *Environ. Behav.* 2(1): 100–117.

Astur RS, Taylor LB, Mamelak AN, Philpott L, and Sutherland RJ (2002) Humans with hippocampus damage display severe spatial memory impairments in a virtual Morris water task. *Behav. Brain Res.* 132(1): 77–84.

Barrash J, Damasio H, Adolphs R, and Tranel D (2000) The neuroanatomical correlates of route learning impairment. *Neuropsychologia* 38(6): 820–836.

Bohbot VD, Iaria G, and Petrides M (2004) Hippocampal function and spatial memory: Evidence from functional neuroimaging in healthy participants and performance of patients with medial temporal lobe resections. *Neuropsychology* 18(3): 418–425.

Bohbot VD, Kalina M, Stepankova K, Spackova N, Petrides M, and Nadel L (1998) Spatial memory deficits in patients with lesions to the right hippocampus and to the right parahippocampal cortex. *Neuropsychologia* 36(11): 1217–1238.

Bremner JG (1978) Spatial errors made by infants: Inadequate spatial cues or evidence of egocentrism? *Br. J. Psychol.* 69(1): 77–84.

Bremner JG and Bryant PE (1977) Place versus response as the basis of spatial errors made by young infants. *J. Exp. Child Psychol.* 23(1): 162–171.

Brewer JB, Zhao Z, Desmond JE, Glover GH, and Gabrieli JD (1998) Making memories: Brain activity that predicts how well visual experience will be remembered. *Science* 281(5380): 1185–1187.

Bryant DJ and Tversky B (1999) Mental representations of perspective and spatial relations from diagrams and models. *J. Exp. Psychol. Learn. Mem. Cogn.* 25(1): 137–156.

Burgess N (2002) The hippocampus, space, and viewpoints in episodic memory. *Q. J. Exp. Psychol.* 55A(4): 1057–1080.

Burgess N, Becker S, King J, and O'Keefe J (2001) Memory for events and their spatial context: Models and experiments. *Philos. Trans. R. Soc. Lond. B Biol. Sci.,* 356(1413): 1493–1503.

Burgess N, Spiers HJ, and Paleologou E (2004) Orientational manoeuvres in the dark: Dissociating allocentric and egocentric influences on spatial memory. *Cognition* 94(2): 149–166.

Bushnell EW, McKenzie BE, Lawrence DA, and Connell S (1995) The spatial coding strategies of one-year-old infants in a locomotor search task. *Child Dev.* 66(4): 937–958.

Byrne P, Becker S, and Burgess N (2007) Remembering the past and imagining the future: A neural model of spatial memory and imagery. *Psychol. Rev.* 114(2): 340–375.

Byrne RW (1979) Memory for urban geography. *Q. J. Exp. Psychol.* 31(1): 147–154.

Campos JJ, Anderson DI, Barbu Roth MA, Hubbard EM, Hertenstein MJ, and Witherington D (2000) Travel broadens the mind. *Infancy* 1(2): 149–219.

Carbon CC and Leder H (2005) The Wall inside the brain: Overestimation of distances crossing the former Iron Curtain. *Psychon. Bull. Rev.* 12(4): 746–750.

Chance SS, Gaunet F, Beall AC, and Loomis JM (1998) Locomotion mode affects the updating of objects encountered during travel: The contribution of vestibular and proprioceptive inputs to path integration. *Presence Teleoperators Virtual Environ.* 7(2): 168–178.

Cheng K (1986) A purely geometric module in the rat's spatial representation. *Cognition* 23(2): 149–178.

Cheng K and Newcombe NS (2005) Is there a geometric module for spatial orientation? Squaring theory and evidence. *Psychon. Bull. Rev.* 12(1): 1–23.

Colby CL and Goldberg ME (1999) Space and attention in parietal cortex. *Annu. Rev. Neurosci.* 22, 319–349.

Cornell EH and Greidanus E (2006) Path integration during a neighborhood walk. *Spat. Cogn. Comput.* 6(3): 203–234.

Cornell EH and Heth CD (2004) Memories of travel: Dead reckoning within the cognitive map. In: Allen GL (ed.) *Human Spatial Memory: Remembering Where*, pp. 191–215. Mahwah, NJ: Lawrence Erlbaum Associates.

Cornell EH, Heth CD, and Rowat WL (1992) Wayfinding by children and adults: Response to instructions to use look-back and retrace strategies. *Dev. Psychol.* 28(2): 328–336.

Couclelis H, Golledge RG, Gale N, and Tobler W (1987) Exploring the anchor-point hypothesis of spatial cognition. *J. Environ. Psychol.* 7, 99–122.

DeLoache JS and Brown AL (1983) Very young children's memory for the location of objects in a large-scale environment. *Child Dev.* 54(4): 888–897.

Diwadkar VA and McNamara TP (1997) Viewpoint dependence in scene recognition. *Psychol. Sci.* 8(4): 302–307.

Easton RD and Sholl MJ (1995) Object-array structure, frames of reference, and retrieval of spatial knowledge. *J. Exp. Psychol. Learn. Mem. Cogn.* 21(2): 483–500.

Ekstrom AD, Kahana MJ, Caplan JB, et al. (2003) Cellular networks underlying human spatial navigation. *Nature* 425(6954): 184–187.

Epstein RA (2005) The cortical basis of visual scene processing. *Vis. Cogn.* 12(6): 954–978.

Epstein RA, DeYoe EA, Press DZ, Rosen AC, and Kanwisher N (2001) Neuropsychological evidence for a topographical learning mechanism in parahippocampal cortex. *Cogn. Neuropsychol.* 18(6): 481–508.

Epstein RA, Graham KS, and Downing PE (2003) Viewpoint-specific scene representations in human parahippocampal cortex. *Neuron* 37(5): 865–876.

Epstein RA, Harris A, Stanley D, and Kanwisher N (1999) The parahippocampal place area: Recognition, navigation, or encoding? *Neuron* 23(1): 115–125.

Epstein RA, Higgins JS, and Thompson Schill SL (2005) Learning places from views: Variation in scene processing as a function of experience and navigational ability. *J. Cogn. Neurosci.* 17(1): 73–83.

Epstein RA and Kanwisher N (1998) A cortical representation of the local visual environment. *Nature* 392(6676): 598–601.

Evans GW and Pezdek K (1980) Cognitive mapping: Knowledge of real-world distance and location information. *J. Exp. Psychol. [Hum. Learn.]* 6(1): 13–24.

Farrell MJ and Robertson IH (1998) Mental rotation and automatic updating of body-centered spatial relationships. *J. Exp. Psychol. Learn. Mem. Cogn.* 24(1): 227–233.

Farrell MJ and Thomson JA (1998) Automatic spatial updating during locomotion without vision. *Q. J. Exp. Psychol. A* 51(3): 637–654.

Foo P, Warren WH, Duchon A, and Tarr MJ (2005) Do humans integrate routes into a cognitive map? Map- versus landmark-based navigation of novel shortcuts. *J. Exp. Psychol. Learn. Mem. Cogn.* 31(2): 195–215.

Franklin N and Tversky B (1990) Searching imagined environments. *J. Exp. Psychol. Gen.* 119(1): 63–76.

Friedman A and Brown NR (2000) Reasoning about geography. *J. Exp. Psychol. Gen.* 129(2): 193–219.

Friedman A, Brown NR, and McGaffey AP (2002) A basis for bias in geographical judgments. *Psychon. Bull. Rev.* 9(1): 151–159.

Friedman A and Montello DR (2006) Global-scale location and distance estimates: Common representations and strategies in absolute and relative judgments. *J. Exp. Psychol. Learn. Mem. Cogn.* 32(2): 333–346.

Gallistel CR (1990) *The Organization of Learning*. Cambridge, MA: MIT Press.

Gärling T, Book A, Lindberg E, and Nilsson T (1981) Memory for the spatial layout of the everyday physical environment: Factors affecting rate of acquisition. *J. Environ. Psychol.* 1(4): 263–277.

Golledge RG (1993) Integrating route knowledge in an unfamiliar neighborhood: Along and across route experiments. *J. Environ. Psychol.* 13(4): 293–307.

Golledge RG (1999) Human wayfinding and cognitive maps. In: Golledge RG (ed.) *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*, pp. 5–45. Baltimore, MD: Johns Hopkins University Press.

Gouteux S and Spelke ES (2001) Children's use of geometry and landmarks to reorient in an open space. *Cognition,* 81(2): 119–148.

Hafting T, Fyhn M, Molden S, Moser MB, and Moser EI (2005) Microstructure of a spatial map in the entorhinal cortex. *Nature* 436(7052): 801–806.

Hart RA and Moore GT (1973) The development of spatial cognition: A review. In: Downs RM and Stea D (eds.) *Image and Environment*, pp. 246–288. Chicago: Aldine Publishing.

Hartley T, Trinkler I, and Burgess N (2004) Geometric determinants of human spatial memory. *Cognition,* 94(1): 39–75.

Hermer L and Spelke ES (1994) A geometric process for spatial reorientation in young children. *Nature* 370(6484): 57–59.

Hermer L and Spelke ES (1996) Modularity and development: The case of spatial reorientation. *Cognition* 61(3): 195–232.

Hermer-Vazquez L, Moffet A, and Munkholm P (2001) Language, space, and the development of cognitive flexibility in humans: The case of two spatial memory tasks. *Cognition* 79(3): 263–299.

Hintzman DL, O'Dell CS, and Arndt DR (1981) Orientation in cognitive maps. *Cogn. Psychol.* 13: 149–206.

Hirtle SC and Jonides J (1985) Evidence of hierarchies in cognitive maps. *Mem. Cognit.* 13(3): 208–217.

Hodgson E and Waller D (2006) Lack of set size effects in spatial updating: Evidence for offline updating. *J. Exp. Psychol. Learn. Mem. Cogn.* 32(4): 854–866.

Holdstock JS, Mayes AR, Cezayirli E, Isaac CL, Aggleton JP, and Roberts N (2000) A comparison of egocentric and allocentric spatial memory in a patient with selective hippocampal damage. *Neuropsychologia* 38(4): 410–425.

Holmes MC and Sholl MJ (2005) Allocentric coding of object-to-object relations in overlearned and novel environments. *J. Exp. Psychol. Learn. Mem. Cogn.* 31(5): 1069–1087.

Hund AM and Spencer JP (2003) Developmental changes in the relative weighting of geometric and experience-dependent location cues. *J. Cogn. Dev.* 4(1): 3–38.

Hupbach A and Nadel L (2005) Reorientation in a rhombic environment: No evidence for an encapsulated geometric module. *Cogn. Dev.* 20(2): 279–302.

Huttenlocher J, Hedges LV, and Duncan S (1991) Categories and particulars: Prototype effects in estimating spatial location. *Psychol. Rev.* 98(3): 352–376.

Huttenlocher J and Vasilyeva M (2003) How toddlers represent enclosed spaces. *Cogn. Sci.* 27(5): 749–766.

Ishikawa T and Montello DR (2006) Spatial knowledge acquisition from direct experience in the environment: Individual differences in the development of metric knowledge and the integration of separately learned places. *Cogn. Psychol.* 52(2): 93–129.

Kearns MJ, Warren WH, Duchon AP, and Tarr M (2002) Path integration from optic flow and body senses in a homing task. *Perception* 31(3): 349–374.

Kesner RP and Hopkins RO (2001) Short-term memory for duration and distance in humans: Role of the hippocampus. *Neuropsychology* 15(1): 58–68.

Klatzky RL (1998) Allocentric and egocentric spatial representations: Definitions, distinctions, and interconnections. In: Freksa C, Habel C, and Wender KF (eds.) *Spatial Cognition: An Interdisciplinary Approach to Representing and Processing Spatial Knowledge*, pp. 1–17. Berlin: Springer.

Klatzky RL, Loomis JM, Beall AC, Chance SS, and Golledge RG (1998) Spatial updating of self-position and orientation during real, imagined, and virtual locomotion. *Psychol. Sci.* 9(4): 293–298.

Klatzky RL, Loomis JM, Golledge RG, Cicinelli JG, Doherty S, and Pellegrino JW (1990) Acquisition of route and survey knowledge in the absence of vision. *J. Mot. Behav.* 22(1): 19–43.

Kosslyn SM, Pick HL, Jr., and Fariello GR (1974) Cognitive maps in children and men. *Child Dev.* 45(3): 707–716.

Landau B and Spelke ES (1988) Geometric complexity and object search in infancy. *Dev. Psychol.* 24(4): 512–521.

Learmonth AE, Nadel L, and Newcombe NS (2002) Children's use of landmarks: Implications for modularity theory. *Psychol. Sci.* 13(4): 337–341.

Learmonth AE, Newcombe NS, and Huttenlocher J (2001) Toddlers' use of metric information and landmarks to reorient. *J. Exp. Child Psychol.* 80(3): 225–244.

Lee SA, Shusterman A, and Spelke ES (2006) Reorientation and landmark-guided search by young children: Evidence for two systems. *Psychol. Sci.* 17(7): 577–582.

Levinson SC (1996) Frames of reference and Molyneux's question: Cross-linguistic evidence. In: Bloom P, Peterson MA, Nadel L, and Garrett MF (eds.) *Language and Space*, pp. 109–169. Cambridge, MA: MIT Press.

Lew AR, Foster KA, Crowther HL, and Green M (2004) Indirect landmark use at 6 months of age in a spatial orientation task. *Infant Behav. Dev.* 27(1): 81–90.

Loomis JM and Beall AC (1998) Visually controlled locomotion: Its dependence on optic flow, three-dimensional space perception, and cognition. *Ecol. Psychol.* 10(3–4): 271–285.

Loomis JM, Klatzky RL, Golledge RG, Cicinelli JG, Pellegrino JW, and Fry PA (1993) Nonvisual navigation by blind and sighted: Assessment of path integration ability. *J. Exp. Psychol. Gen.* 122(1): 73–91.

Loomis JM, Klatzky RL, Golledge RG, and Philbeck JW (1999) Human navigation by path integration. In: Golledge RG (ed.) *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*, pp. 125–151. Baltimore, MD: Johns Hopkins University Press.

Lourenco SF, Huttenlocher J, and Vasilyeva M (2005) Toddlers' representations of space. *Psychol. Sci.* 16(4): 255–259.

Luzzi S, Pucci E, Di Bella P, and Piccirilli M (2000) Topographical disorientation consequent to amnesia of spatial location in a patient with right parahippocampal damage. *Cortex,* 36(3): 427–434.

Lynch K (1960) *The Image of the City*. Cambridge, MA: MIT Press.

MacDonald SE, Spetch ML, Kelly DM, and Cheng K (2004) Strategies in landmark use by children, adults, and marmoset monkeys. *Learn. Motiv.* 35(4): 322–347.

Maguire EA, Frackowiak RS, and Frith CD (1996) Learning to find your way: A role for the human hippocampal formation. *Proc. R. Soc. Lond. B Biol. Sci.* 263(1377): 1745–1750.

Maguire EA, Frackowiak RSJ, and Frith CD (1997) Recalling routes around London: Activation of the right hippocampus in taxi drivers. *J. Neurosci.* 17(18): 7103–7110.

Maguire EA, Frith CD, Burgess N, Donnett JG, and O'Keefe J (1998) Knowing where things are: Parahippocampal involvement in encoding object relations in virtual large-scale space. *J. Cogn. Neurosci.* 10(1): 61–76.

Maki RH (1981) Categorization and distance effects with spatial linear orders. *J. Exp. Psychol. [Hum. Learn.]* 7(1): 15–32.

Malkova L and Mishkin M (2003) One-trial memory for object-place associations after separate lesions of hippocampus and posterior parahippocampal region in the monkey. *J. Neurosci.* 23(5): 1956–1965.

Marr D (1982) *Vision*. San Francisco: W. H. Freeman.

Matsumura N, Nishijo H, Tamura R, Eifuku S, Endo S, and Ono T (1999) Spatial- and task-dependent neuronal responses during real and virtual translocation in the monkey hippocampal formation. *J. Neurosci.* 19(6): 2381–2393.

May M (1996) Cognitive and embodied modes of spatial imagery. *Psychol. Beitr.* 38(3–4): 418–434.

May M (2004) Imaginal perspective switches in remembered environments: Transformation versus interference accounts. *Cogn. Psychol.* 48(2): 163–206.

May M and Klatzky RL (2000) Path integration while ignoring irrelevant movement. *J. Exp. Psychol. Learn. Mem. Cogn.* 26(1): 169–186.

McNamara TP (1986) Mental representations of spatial relations. *Cogn. Psychol.* 18(1): 87–121.

McNamara TP (2003) How are the locations of objects in the environment represented in memory? In: Freksa C, Brauer W, Habel C, and Wender KF (eds.) *Spatial Cognition III: Routes and Navigation, Human Memory and Learning, Spatial Representation and Spatial Reasoning, LNAI* 2685, pp. 174–191. Berlin: Springer.

McNamara TP and Diwadkar VA (1997) Symmetry and asymmetry of human spatial memory. *Cogn. Psychol.* 34(2): 160–190.

McNamara TP, Hardy JK, and Hirtle SC (1989) Subjective hierarchies in spatial memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 15(2): 211–227.

McNamara TP, Ratcliff R, and McKoon G (1984) The mental representation of knowledge acquired from maps. *J. Exp. Psychol. Learn. Mem. Cogn.* 10(4): 723–732.

Mellet E, Bricogne S, Tzourio-Mazoyer N, et al. (2000) Neural correlates of topographic mental exploration: The impact of route versus survey perspective learning. *Neuroimage* 12(5): 588–600.

Moar I and Bower GH (1983) Inconsistency in spatial knowledge. *Mem. Cognit.* 11(2): 107–113.

Montello DR (1998) A new framework for understanding the acquisition of spatial knowledge in large-scale environments. In: Egenhofer MJ and Golledge RG (eds.) *Spatial and Temporal Reasoning in Geographic Information Systems*, pp. 143–154. New York: Oxford University Press.

Montello DR (2005) Navigation. In: Shah P and Miyake A (eds.) *The Cambridge Handbook of Visuospatial Thinking*, pp. 257–294. New York: Cambridge University Press.

Montello DR and Golledge RG (1999) *Scale and Detail in the Cognition of Geographic Information.* Report of Specialist Meeting of Project Varenius held May 14–16, 1998, in Santa Barbara, CA. University of California at Santa Barbara.

Montello DR and Pick HL (1993) Integrating knowledge of vertically aligned large-scale spaces. *Environ. Behav.* 25(4): 457–484.

Mou W and McNamara TP (2002) Intrinsic frames of reference in spatial memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 28(1): 162–170.

Mou W, McNamara TP, Rump B, and Xiao C (2006) Roles of egocentric and allocentric spatial representations in locomotion and reorientation. *J. Exp. Psychol. Learn. Mem. Cogn.* 32(6): 1274–1290.

Mou W, McNamara TP, Valiquette CM, and Rump B (2004) Allocentric and egocentric updating of spatial memories. *J. Exp. Psychol. Learn. Mem. Cogn.* 30(1): 142–157.

Mou W, Zhao M, and McNamara TP (2007) Layout Geometry in the Selection of Intrinsic Frames of Reference From Multiple Viewpoints. *J. Exp. Psychol. Learn. Mem. Cogn.* 33(1): 145–154.

Nardini M, Burgess N, Breckenridge K, and Atkinson J (2006) Differential developmental trajectories for egocentric, environmental and intrinsic frames of reference in spatial memory. *Cognition* 101(1): 153–172.

Newcombe NS and Huttenlocher J (2000) *Making Space: The Development of Spatial Representation and Reasoning*. Cambridge, MA: The MIT Press.

Newcombe NS and Huttenlocher J (2006) Development of spatial cognition. In: Kuhn D, Siegler RS, Damon W, and Lerne RM (eds.) *Handbook of Child Psychology: Vol. 2, Cognition, Perception, and Language,* 6th edn., pp. 734–776. Hoboken, NJ: John Wiley and Sons Inc.

Newcombe NS, Huttenlocher J, Drummey AB, and Wiley JG (1998) The development of spatial location coding: Place learning and dead reckoning in the second and third years. *Cogn. Dev.* 13(2): 185–200.

Newcombe NS, Huttenlocher J, Sandberg E, Lie E, and Johnson S (1999) What do misestimations and asymmetries in spatial judgement indicate about spatial representation? *J. Exp. Psychol. Learn. Mem. Cogn.* 25(4): 986–996.

Newcombe NS and Liben LS (1982) Barrier effects in the cognitive maps of children and adults. *J. Exp. Child Psychol.* 34(1): 46–58.

O'Keefe J and Dostrovsky J (1971) The hippocampus as a spatial map: Preliminary evidence from unit activity in the freely-moving rat. *Brain Res.* 34, 171–175.

O'Keefe J and Nadel L (1978) *The Hippocampus As a Cognitive Map*. Oxford: Clarendon Press.

Paillard J (*ed*.) (1991) *Brain and Space*. New York: Oxford University Press.

Pani JR and Dupree D (1994) Spatial reference systems in the comprehension of rotational motion. *Perception* 23(8): 929–946.

Parkinson JK, Murray EA, and Mishkin M (1988) A selective mnemonic role for the hippocampus in monkeys: Memory for the location of objects. *J. Neurosci.* 8(11): 4159–4167.

Parslow DM, Rose D, Brooks B, et al. (2004) Allocentric spatial memory activation of the hippocampal formation measured with fMRI. *Neuropsychology* 18(3): 450–461.

Péruch P, May M, and Wartenberg F (1997) Homing in virtual environments: Effects of field of view and path layout. *Perception* 26(3): 301–311.

Philbeck JW, Klatzky RL, Behrmann M, Loomis JM, and Goodridge J (2001) Active control of locomotion facilitates nonvisual navigation. *J. Exp. Psychol. Hum. Percept. Perform.* 27(1): 141–153.

Pick HL, Jr., Rieser JJ, Wagner D, and Garing AE (1999) The recalibration of rotational locomotion. *J. Exp. Psychol. Hum. Percept. Perform.* 25(5): 1179–1188.

Poucet B (1993) Spatial cognitive maps in animals: New hypotheses on their structure and neural mechanisms. *Psychol. Rev.* 100(2): 163–182.

Presson CC, DeLange N, and Hazelrigg MD (1989) Orientation specificity in spatial memory: What makes a path different from a map of the path? *J. Exp. Psychol. Learn. Mem. Cogn.* 15(5): 887–897.

Presson CC and Hazelrigg MD (1984) Building spatial representations through primary and secondary learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 10(4): 716–722.

Presson CC and Montello DR (1994) Updating after rotational and translational body movements: Coordinate structure of perspective space. *Perception* 23(12): 1447–1455.
Reitman JS and Rueter HH (1980) Organization revealed by recall orders and confirmed by pauses. *Cogn. Psychol.* 12(4): 554–581.
Richardson AE, Montello DR, and Hegarty M (1999) Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Mem. Cognit.* 27(4): 741–750.
Riecke BE, van Veen HAHC, and Bülthoff HH (2002) Visual homing is possible without landmarks: A path integration study in virtual reality. *Presence Teleoperators Virtual Environ.* 11(5): 443–473.
Rieser JJ (1979) Spatial orientation of six-month-old infants. *Child Dev.* 50(4): 1078–1087.
Rieser JJ (1989) Access to knowledge of spatial structure at novel points of observation. *J. Exp. Psychol. Learn. Mem. Cogn.* 15(6): 1157–1165.
Rieser JJ (1999) Dynamic spatial orientation and the coupling of representation and action. In: Golledge R (ed.) *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*, pp. 168–190. Baltimore, MD: Johns Hopkins University Press.
Rieser JJ (2000) Concepts about the causes of development: Travel, visual experience, and the development of dynamic spatial orientation. *Infancy* 1(2): 231–238.
Rieser JJ and Pick HL, Jr. (2006) Perception-action-representation systems using movement to update spatial orientation: What changes with learning and development? In: Plumert JM and Spencer JP (eds.) *The Emerging Spatial Mind*. London: Oxford University Press.
Rieser JJ and Rider EA (1991) Young children's spatial orientation with respect to multiple targets when walking without vision. *Dev. Psychol.* 27(1): 97–107.
Rieser JJ, Guth DA, and Hill EW (1986) Sensitivity to perspective structure while walking without vision. *Perception* 15(2): 173–188.
Rieser JJ, Pick HL, Ashmead DH, and Garing AE (1995) Calibration of human locomotion and models of perceptual-motor organization. *J. Exp. Psychol. Hum. Percept. Perform.* 21(3): 480–497.
Rock I (1973) *Orientation and Form*. New York: Academic Press.
Rock I (1992) Comment on Asch and Witkin's ''Studies in space orientation: II.'' *J. Exp. Psychol. Gen.* 121(4): 404–406.
Ruddle RA and Lessels S (2006) For efficient navigational search, humans require full physical movement, but not a rich visual scene. *Psychol. Sci.* 17(6): 460–465.
Ruddle RA and Péruch P (2004) Effects of proprioceptive feedback and environmental characteristics on spatial learning in virtual environments. *Int. J. Hum. Comput. Stud.* 60(3): 299–306.
Sadalla EK, Burroughs WJ, and Staplin LJ (1980) Reference points in spatial cognition. *J. Exp. Psychol. [Hum. Learn.]* 6(5): 516–528.
Sadalla EK and Magel SG (1980) The perception of traversed distance. *Environ. Behav.* 12(1): 65–79.
Sadalla EK and Montello DR (1989) Remembering changes in direction. *Environ. Behav.* 21(3): 346–363.
Sadalla EK and Staplin LJ (1980) The perception of traversed distance: Intersections. *Environ. Behav.* 12(2): 167–182.
Sandstrom NJ, Kaufman J, and Huettel SA (1998) Males and females use different distal cues in a virtual environment navigation task. *Cogn. Brain Res.* 6(4): 351–360.
Schmidt T and Lee EY (2006) Spatial memory organized by environmental geometry. *Spat. Cogn. Comput.* 6(4): 347–369.
Shelton AL and Gabrieli JDE (2002) Neural correlates of encoding space from route and survey perspectives. *J. Neurosci.* 22(7): 2711–2717.
Shelton AL and Gabrieli JDE (2004) Neural correlates of individual differences in spatial learning strategies. *Neuropsychology* 18(3): 442–449.
Shelton AL and McNamara TP (2001) Systems of spatial reference in human memory. *Cogn. Psychol.* 43(4): 274–310.
Sholl MJ (1989) The relation between horizontality and rod-and-frame and vestibular navigational performance. *J. Exp. Psychol. Learn. Mem. Cogn.* 15(1): 110–125.
Sholl MJ (2001) The role of a self-reference system in spatial navigation. In: Montello D (ed.) *Proceedings of the COSIT International Conference: Vol. 2205. Spatial Information Theory: Foundations of Geographic Information Science*, pp. 217–232. Berlin: Springer.
Sholl MJ and Nolin TL (1997) Orientation specificity in representations of place. *J. Exp. Psychol. Learn. Mem. Cogn.* 23(6): 1494–1507.
Siegel AW and White SH (1975) The development of spatial representations of large-scale environments. In: Reese HW (ed.) *Advances in Child Development and Behavior,* vol. 10, pp. 9–55. New York: Academic Press.
Snyder LH, Grieve KL, Brotchie P, and Andersen RA (1998) Separate body- and world-referenced representations of visual space in parietal cortex. *Nature* 394(6696): 887–891.
Stark M, Coslett HB, and Saffran EM (1996) Impairment of an egocentric map of locations: Implications for perception and action. *Cogn. Neuropsychol.* 13(4): 481–523.
Stepankova K, Fenton AA, Pastalkova E, Kalina M, and Bohbot VD (2004) Object-location memory impairment in patients with thermal lesions to the right or left hippocampus. *Neuropsychologia* 42(8): 1017–1028.
Stevens A and Coupe P (1978) Distortions in judged spatial relations. *Cogn. Psychol.* 10(4): 422–437.
Talmy L (1983) How language structures space. In: Pick JHL and Acredolo LP (eds.) *Spatial Orientation: Theory, Research and Application*, pp. 225–282. New York: Plenum.
Thorndyke PW (1981) Distance estimation from cognitive maps. *Cogn. Psychol.* 13(4): 526–550.
Thorndyke PW and Hayes-Roth B (1982) Differences in spatial knowledge acquired from maps and navigation. *Cogn. Psychol.* 14(4): 560–589.
Tolman EC (1948) Cognitive maps in rats and men. *Psychol. Rev.* 55(4): 189–208.
Tversky B (1981) Distortions in memory for maps. *Cogn. Psychol.* 13(3): 407–433.
Tversky B (1992) Distortions in cognitive maps. *Geoforum* 23(2): 131–138.
Tversky B (2000) Remembering spaces. In: Tulving E and Craik FIM (eds.), *The Oxford Handbook of Memory*, pp. 363–378. New York: Oxford University Press.
Tversky B, Lee P, and Mainwaring S (1999) Why do speakers mix perspectives? *Spat. Cogn. Comput.* 1(4): 399–412.
Valiquette CM and McNamara TP (2007) Different mental representations for place recognition and goal localization. *Psychon. Bull. Rev.* 14(4): 676–680.
Valiquette CM, McNamara TP, and Labrecque JS (2007) Biased representations of the spatial structure of navigable environments. *Psychol. Res.* 71(3): 288–297.
Vetter T, Poggio T, and Bulthoff HH (1994) The importance of symmetry and virtual views in three-dimensional object recognition. *Curr. Biol.* 4(1): 18–23.
Waller D (2006) Egocentric and nonegocentric coding in memory for spatial layout: Evidence from scene recognition. *Mem. Cognit.* 34(3): 491–504.
Waller D and Hodgson E (2006) Transient and enduring spatial representations under disorientation and self-rotation. *J. Exp. Psychol. Learn. Mem. Cogn.* 32(4): 867–882.
Waller D, Loomis JM, and Haun DBM (2004) Body-based senses enhance knowledge of directions in large-scale environments. *Psychon. Bull. Rev.* 11(1): 157–163.

Waller D, Montello DR, Richardson AE, and Hegarty M (2002) Orientation specificity and spatial updating of memories for layouts. *J. Exp. Psychol. Learn. Mem. Cogn.* 28(6): 1051–1063.

Wang RF (2004) Between reality and imagination: When is spatial updating automatic? *Percept. Psychophys.* 66(1): 68–76.

Wang RF and Brockmole JR (2003a) Human navigation in nested environments. *J. Exp. Psychol. Learn. Mem. Cogn.* 29(3): 398–404.

Wang RF and Brockmole JR (2003b) Simultaneous spatial updating in nested environments. *Psychon. Bull. Rev.* 10(4): 981–986.

Wang RF, Crowell JA, Simons DJ, et al. (2006) Spatial updating relies on an egocentric representation of space: Effects of the number of objects. *Psychon. Bull. Rev.* 13(2): 281–286.

Wang RF and Simons DJ (1999) Active and passive scene recognition across views. *Cognition* 70(2): 191–210.

Wang RF and Spelke ES (2000) Updating egocentric representations in human navigation. *Cognition* 77(3): 215–250.

Wang RF and Spelke ES (2002) Human spatial representation: Insights from animals. *Trends Cogn. Sci.* 6(9): 376–382.

Wehner R, Michel B, and Antonsen P (1996) Visual navigation in insects: Coupling of egocentric and geocentric information. *J. Exp. Biol.* 199, 129–140.

Werner S and Long P (2003) Cognition meets Le Corbusier: Cognitive principles of architectural design. In: Freksa C, Brauer W, Habel C, and Wender KF (eds.) *Spatial Cognition III: Routes and Navigation, Human Memory and Learning, Spatial Representations and Spatial Learning*, pp. 112–126. Berlin: Springer.

Werner S and Schindler LE (2004) The role of spatial reference frames in architecture: Misalignment impairs way-finding performance. *Environ. Behav.* 36(4): 461–482.

Wiener JM and Mallot HA (2003) 'Fine-to-Coarse' route planning and navigation in regionalized environments. *Spat. Cogn. Comput.* 3(4): 331–358.

Wiener JM, Schnee A, and Mallot HA (2004) Use and interaction of navigation strategies in regionalized environments. *J. Environ. Psychol.* 24(4): 475–493.

Wilton RN (1979) Knowledge of spatial relations: The specification of the information used in making inferences. *Q. J. Exp. Psychol.* 31(1): 133–146.

Wraga M (2003) Thinking outside the body: An advantage for spatial updating during imagined versus physical self-rotation. *J. Exp. Psychol. Learn. Mem. Cogn.* 29(5): 993–1005.

Wraga M, Creem-Regehr SH, and Proffitt DR (2004) Spatial updating of virtual displays during self- and display rotation. *Mem. Cogn.* 32(3): 399–415.

Yardley L and Higgins M (1998) Spatial updating during rotation: The role of vestibular information and mental activity. *J. Vestib. Res.* 8(6): 435–442.

# 2.12 Forgetting

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## 2.12.1 Introduction

As Ebbinghaus observed in his famous monograph, "Left to itself every mental content gradually loses its capacity for being revived, or at least suffers loss in this regard under the influence of time" (1885/1964: 4). To most, forgetting is a scourge, a nuisance, a breakdown in an otherwise efficient mental capacity. The momentary loss of information is a regular part of the human experience, but normal forgetting, even when permanent, is misconstrued as a malfunction or breakdown. We forget for adaptive reasons, and understanding the characteristics of forgetting ultimately tells us a great deal about why and how we remember.

In this chapter we offer a general tutorial on the psychology of forgetting. Our focus will be on its empirical characteristics and proposed theoretical underpinnings, as revealed primarily through laboratory studies with healthy human participants. Excellent reviews on abnormal forms of forgetting, such as those that occur in brain-damaged patients, and on forgetting in nonhuman populations can be found elsewhere in this series. We begin the chapter with a brief discussion of the adaptive value of forgetting, followed by an examination of its functional and mathematical characteristics. Next, we discuss possible causal mechanisms in some detail – why do we forget? Finally, we end by reconsidering the meaning of forgetting and its proper role in modern memory theory.

## 2.12.2 Forgetting and Its Adaptive Value

At face value, memory seems to be about recovering the past, recapturing or reviving previous experiences. Yet, it is unlikely that memory actually evolved for this specific purpose. The past can never occur again, at least in exactly the same form, so there is limited adaptive value in developing a system that carries around intact records of prior experiences. Instead, memory has value because it allows us to use the past in the service of the present, to decide on an appropriate plan of action now or in the future (Suddendorf and Corballis, 1997; Tulving, 2002). Intact records of the past are relevant in some situations, but not in others. For example, we might need to remember the specific location of a food source, but we need not remember every instance in which a particular food type was consumed (we need to remember only that it was edible). As Lewis Carroll famously quipped, "it's a poor sort of memory that only works backwards."

Recognizing that memory's primary function is to deal with the present, or perhaps to anticipate the future, informs how we need to think about forgetting. Obviously, if nature did not 'design' memory to reproduce the literal past, then it is not surprising that we sometimes have difficulty reproducing it. The veridical details of an event tend to be ignored by our memory systems, which choose instead to process and store inferences or connections that are likely to benefit future responding (Bartlett, 1932; Schacter and Addis, 2007). Even when the details of an event are correctly stored, there is little reason to anticipate that those details will be stored indefinitely. In fact, it is easy to make the case that forgetting is a highly adaptive feature of cognition (Bjork and Bjork, 1988, 1996; Altmann and Gray, 2002). Having an intermediate, rather than complete, retention of the past may improve our ability to use inferential heuristics (Schooler and Hertwig, 2005), maximize our ability to detect causality (Kareev, 2000), and even maintain a sense of sanity in an ever-changing world (Luria, 1968).

More to the point, a well-designed memory system can be expected to show sensitivity to the likelihood that a past event will be needed, or appropriate, to a future situation. It makes no sense to retain long-defunct telephone numbers, or high school locker combinations: These are more apt to produce needless clutter than potentially useful records. Moreover, once an event occurs in the present, the likelihood that it will occur again (at least in a similar form) changes predictably with time. If a predator appears in your environment at time $t$, then the chances that it will appear again are usually greater at time $t+1$ than at time $t+2$. As it turns out, the function relating event recurrence with time typically takes a negatively accelerated form, just like the classic forgetting function (Anderson and Schooler, 1991). What we normally think of as forgetting, therefore, may simply represent memory's sensitivity to the statistical structure of events in the environment. We forget an item's occurrence with time because, in fact, that item is less likely to occur again with time.

## 2.12.3 The Characteristics of Forgetting

The fact that forgetting takes on a characteristic form is *prima facie* evidence that a psychological process is at work. We do not forget things randomly; rather, the loss of information proceeds in an understandable

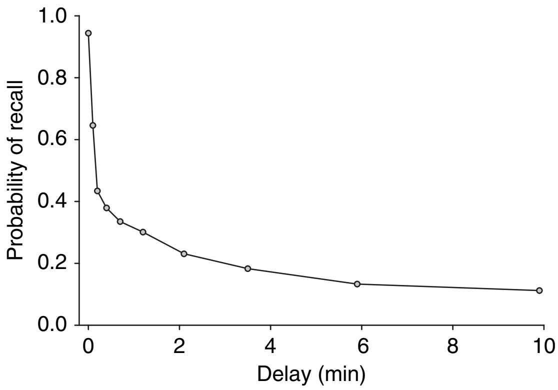


**Figure 1** Probability of correctly recalling a word as a function of time. Data from Rubin DC, Hinton S, and Wenzel AE (1999) The precise time course of retention. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 1161–1176.

and predictable fashion. A typical retention function is shown in **Figure 1** and it contains a stark empirical regularity: There is a negatively accelerating downward loss in retention over time. We forget rapidly at first and then retention slowly levels off. This general pattern occurs regardless of the quantity or quality of the information learned and the retention measure employed.

Ebbinghaus is usually credited with the first empirical demonstration of the forgetting function (although see Galton, 1879). Using his famous savings method, Ebbinghaus recorded the amount of time spent relearning an earlier memory series (usually consisting of nonsense syllables). In one case, he learned eight series of 13 syllables each (to a criterion of two errorless recitations) and then attempted to relearn the same material after one of seven delays ranging from 1 h to 31 days. The percentage savings, calculated as the difference in time spent during initial learning and relearning expressed as a percentage of the original learning time, dropped systematically over delay in a form resembling that shown in **Figure 1**. He expressed some surprise at the form of forgetting, particularly the lessening effect shown at the later delays. Forgetting "in the latter intervals is evidently so slow that it is easy to predict that a complete vanishing of the effect of the first memorization of these series would, if they had been left to themselves, have occurred only after an indefinitely long period of time" (Ebbinghaus, 1885/1964: 76). The question of whether information, once encoded, ever truly vanishes completely (in the absence of relearning or reexposure) remains an issue of concern today (Bahrick, 2000; Wixted, 2004a).

### 2.12.3.1 Forgetting's Mathematical Form

Psychologists have struggled to characterize the forgetting function in more precise mathematical terms. Ebbinghaus suggested a type of logarithmic function, but many candidates are viable. Linear functions can probably be ruled out, along with simple exponentials, but it is possible to salvage most functions with the right set of assumptions. Psychologists usually choose power – logarithmic, exponential power – or hyperbolic functions, but the decision is often driven by theoretical rather than empirical concerns. At present, despite over a century of effort, no firm consensus on the matter has arisen, although currently many researchers lean toward some kind of power function (e.g., Wixted and Carpenter, 2007).

The failure to reach consensus about forgetting's mathematical form is understandable; the enterprise is fraught with difficulties. For example, one needs criteria for choosing one function, or forgetting model, over another. It is possible to evaluate competing functions simply on the basis of a goodness-of-fit measure, which has typically been the criterion of choice (e.g., Anderson and Schooler, 1991; Wixted and Ebbesen, 1991; Rubin and Wenzel, 1996). However, goodness-of-fit measures usually ignore other important factors, such as the complexity of the function and its psychological viability (Roberts and Pashler, 2000; Pitt et al., 2002; Lee, 2004). There are also serious measurement concerns. The assessment of forgetting requires tracking performance through different points along the measurement scale. Can we really be certain that a drop in retention from, say, 90% correct to 80% correct means the same thing psychologically as a drop from 20% to 10%?

There is also enormous imprecision in the existing data. Forgetting experiments are hard to conduct. Longitudinal studies require testing the same individual at different retention intervals, which is practically difficult and can introduce a testing, or repeated retrieval, confound. In fact, repeated testing of the same information can actually improve overall performance under some conditions (e.g., hypermnesia, Roediger and Challis, 1989). Cross-sectional studies present similar practical difficulties and provide no assurances that the average retention estimates for the different groups accurately represent how forgetting proceeds in an individual (Rubin and Wenzel, 1996; Chechile, 2006). The net result is that most studies report only a handful of retention intervals and, for obvious reasons, the longest sampled retention interval rarely provides any true estimate of memory's permanence. Some memories may remain intact over a lifetime (Bahrick, 1984, 2000) which, in turn, places important constraints on the retention functions that can apply (Wixted, 2004a; Chechile, 2006). Similarly, one cannot ignore performance when the retention interval approaches zero (i.e., immediate testing); some functions are ill-defined at this point, and it is conceivable that special short-term or working memory systems complicate the retention function at very short retention intervals (Chechile, 2006).

There is also the issue of the proper retention measure. As noted, Ebbinghaus measured retention through savings in relearning, but there are many other measurement tools. One can assess memory through proportion correct recall, the d′ discriminability index in recognition, or through various indices of priming in implicit or indirect retention measures. The retrieval environment can also be enriched through the introduction of retrieval cues or degraded through the presence of other concurrent tasks. In addition, it is unclear whether delay should be defined as the simple passage of time, time calculated in terms of some kind of relative index (Bjork and Whitten, 1974; Baddeley, 1976), or perhaps the number or quality of intervening events (Waugh and Norman, 1965). Time and events are usually confounded because the passage of time is highly correlated with the number of intervening events (Chechile, 1987).

Despite these difficulties, when an empirical forgetting function is obtained it virtually always resembles the one shown in **Figure 1**. We forget rapidly at first and then retention slowly levels off. Empirically, the proportional rate of forgetting also slows over time, as aptly expressed in Jost's famous law of forgetting: "Given two associations of the same strength, but of different ages, the older falls off less rapidly in a given length of time" (Jost, 1897: 472). Younger memory traces, at least on average, are more vulnerable to the deleterious effects of time than older traces. Note that Jost's law conflicts with simple exponential forgetting functions, which assume constant proportional loss. In an exponential function, the proportional rate of loss remains constant (retention falls by 50% between $t$ and $t+\text{k}$, where k corresponds to the function's half-life), so associations of equal strength, regardless of their age, should decline subsequently at the same rate. They do not, and this places important constraints on the possible mechanisms that underlie forgetting.

## 2.12.4 Determinants of Forgetting Rates

It is possible to reconcile Jost's law with exponential forgetting if we assume that forgetting rates vary with degree of original learning (Simon, 1966; Wixted, 2004a). For example, if well-learned information is forgotten more slowly than poorly learned information – that is, if the half-life of a memory trace varies with the degree of initial learning – then Jost's law still holds. The possibility that we lose information at a rate determined by its initial strength itself seems imminently reasonable, even intuitive, but it has received little empirical support in the laboratory. Variables that affect acquisition – e.g., word frequency, meaningfulness, similarity, and so forth – typically have little, if any, impact on subsequent forgetting rates (Underwood, 1964; Keppel, 1968).

Slamecka and McElree (1983) allowed the degree of original learning to vary and then assessed retention across several delays. In each case, despite wide differences in original acquisition level, nearly equivalent forgetting slopes were obtained. Importantly, this conclusion held across different retention measures, including free recall, cued recall, category recall, gist recall, and recognition (see **Figure 2**). The same conclusion holds when different mnemonic components or processes are assessed. McBride and Dosher (1999) used Jacoby's process dissociation technique to examine forgetting functions for conscious and automatic components of memory, as a function of the depth of initial processing (semantic vs. graphemic); similar forgetting rates were found for each component, despite differences in the overall level of availability. Even individual difference variables, such as age (Salthouse, 1991) and neurological status (Christensen et al., 1998), commonly fail to produce stark differences in either the form or the rate of forgetting.

These data, among many others, suggest that acquisition and forgetting are not merely two sides of the same coin; rather, variables that affect acquisition may not affect the forgetting process. Forgetting proceeds in its characteristic way, regardless of the retention measure or initial acquisition level, much like the action potential of a neuron, once generated, travels forward in a characteristic (all-or-none) fashion. Of course, this conclusion must be hedged a bit for all the methodological considerations that have been listed; plus, controversies have raged over how to measure the loss of information over

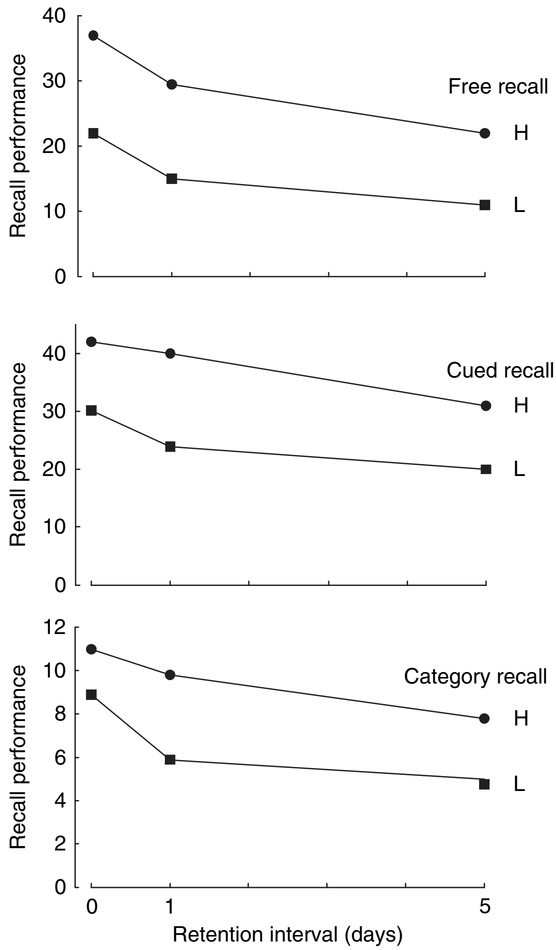


**Figure 2** Forgetting functions obtained for high (H) and low (L) degrees of original learning as revealed for three different retention measures. After Slamecka NJ and McElree B (1983) Normal forgetting of verbal lists as a function of their degree of learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 9: 384–397.

time properly (e.g., Slamecka, 1985; Bogartz, 1990; Loftus and Bamber, 1990). Still, it is generally conceded that forgetting rates remain invariant as acquisition variables, mnemonic processes, and measurement vehicles are manipulated, although exceptions can be found in the literature. For example, McDonald and colleagues (2006) recently found evidence for acquisition-based heterogeneity in forgetting when a novel statistical procedure, multilevel modeling, was applied to the retention data and certain other methodological concerns, such as the mnemonic strategy adopted by the participant, were controlled. The debate continues, as it has for the past century.

## 2.12.5 Mechanisms of Forgetting

It may be difficult to characterize the forgetting function completely, but every researcher recognizes that memory changes systematically with time. As noted earlier, there are excellent reasons to believe that forgetting is adaptive and, more importantly, that the forgetting function mimics the way events occur and recur in the natural world. Consequently, it is reasonable to search for a mechanism, or set of mechanisms, that affects the availability of learned material. Of course, any acceptable theoretical account of why we forget must come to grips with the regularity of the forgetting function itself. One cannot simply argue, for example, that forgetting is cue-dependent – that is, we forget in the absence of an appropriate retrieval cue – without also explaining why the form of forgetting is so regular and predictable.

Historically, researchers have appealed to three primary causal mechanisms to explain forgetting: autonomous decay, interference from other acquired information, and altered stimulus conditions (McGeoch, 1932; Bower and Forgas, 2000). There is a fourth mechanism, active inhibition induced by retrieval, that has been proposed more recently (Bjork and Bjork, 1992; Anderson, 2003), although it, too, has some interesting historical antecedents (e.g., Freud's concept of repression). Each of these mechanisms is discussed in more detail in the sections that follow.

### 2.12.5.1 Decay

When memory theorists use the term *decay*, they mean forgetting that occurs spontaneously with the passage of time. Decay is assumed to be autonomous, which means that its progression does not depend on some other active mnemonic process (such as the acquisition of new information). Of course, everyone believes there must be some kind of neurological underpinning for the decay process, such as a metabolic process that erodes or overwrites synaptic connections, but the mechanism itself is left unspecified. The natural process of radioactive decay is sometimes used as a rough analogy, in which a constant proportion of radioactivity is lost in a fixed unit of time.

To make a principled empirical argument for decay, it is necessary to show that forgetting proceeds in the absence of other activities, such as rehearsal or interference. As we discuss in the next section, newly established memories are quite susceptible to interference from other learned material, so it is necessary to control, if possible, for this factor. Rehearsal also needs to be ruled out, because repetition presumably counteracts the deteriorating effects of the decay process. One needs to create, in essence, a kind of mental vacuum in which time, and little else, is allowed to vary. If information is still forgotten in its characteristic way, then a time-based process, decay, must be responsible.

Various strategies have been employed to detect decay. Most have relied on a dual-task methodology in which the participant is asked to perform an attention-demanding task while simultaneously retaining critical target memories. For example, Reitman (1974) instructed participants to retain groups of words while detecting the occurrence of a tone signal in background noise. The tone detection task was assumed to be sufficiently dissimilar to the words to prevent interference, which typically depends on similarity, and sufficiently taxing to prevent rehearsal (although see Roediger et al., 1977). Similarly, Cowan and colleagues (1997) had people compare the frequencies of two tones separated by delays while performing a silent visual tracking task. It is difficult, perhaps impossible, to rehearse a pure tone, and the intervening visual distractor task seemed unlikely to produce interference, so any decline in the tone task was attributed to decay. In both of these cases, retention performance did decline with delay, implicating decay (although see Cowan et al., 2001).

Note that each of these paradigms investigated retention over the short term, that is, over a time-course of seconds. In fact, the concept of decay is rarely used to explain long-term forgetting, due in large part to the seminal arguments of John McGeoch (1932). Among other things, McGeoch noted that memories often remain highly available or even improve over time, a fact that seems fundamentally incompatible with decay. For example, when people are given repeated opportunities to recall earlier-presented material, they will often recall items on the second or third attempt that they failed to recall initially, a phenomenon known as reminiscence (Ballard, 1913). The Pavlovian phenomenon of spontaneous recovery, in which an extinguished conditioned response recovers after a period of rest, is another case in point (for empirical evidence of spontaneous recovery in human participants, see Wheeler, 1995).

McGeoch (1932) further noted that when the passage of time is held constant, the amount of forgetting depends on the specific activities that occur during the delay. After learning a list of verbal items, if one group of participants rests and a second group learns another list, recovery of the initial list will be sharply impaired in the second group (Müller and Pilzecker, 1900). Moreover, the amount of forgetting will depend on similarity between the original material and the interpolated material (see Osgood, 1953). Forgetting is correlated with the passage of time, McGeoch argued, but the relationship is not causative. It is the events that happen 'in time' that produce forgetting, not time itself.

In the case of short-term retention, however, the situation is somewhat different. Decay remains quite popular among theorists in this arena because short-term retention is thought to tap special storage systems. In the working memory model of Baddeley and Hitch (1974), for example, information is retained for brief intervals in the service of more complex forms of processing (e.g., language), and special 'activity traces' are assumed to be stored in various loops, buffers, and sketchpads (Baddeley, 2000). In the absence of rehearsal, which serves a refreshing function, these traces decay autonomously. Most working memory theorists accept that short-term forgetting can occur as a consequence of other means, such as interference, but decay is assigned an important and even pivotal role (e.g., Page and Norris, 1998).

Memory traces may indeed decay in some circumstances and not in others. There could be something special about short-term activity traces, those engendered and maintained by special short-term memory systems, but the concept remains controversial. For example, Nairne (2002b) has shown that each of McGeoch's main arguments against decay in long-term memory apply equally well to immediate retention: Short-term retention can decline, remain the same, or even improve over time depending on the circumstance. To illustrate, in a study by Turvey et al. (1970), different groups of people were asked to count backward as a distractor activity for group-specific intervals prior to recall (e.g., one group counted for 10 s, another for 15 s, and another for 20 s). Equivalent amounts of forgetting were found across groups in this between-subject design (0.33, 0.30, and 0.30, respectively) (see also Greene, 1996). Moreover, on a critical trial all groups were switched to the same 15-s distractor period. Retention performance dropped in the 10-s group (from 0.33 to 0.20), stayed roughly constant in the 15-s group (0.30 to 0.28), and improved in the 20-s group (0.30 to 0.38). Note that the passage of time – and therefore the opportunity for decay – was equated across the groups on the critical 15-s trial, yet performance depended significantly on the timing of prior trials.

Space does not permit a complete review of all the relevant studies. Suffice to say that the correlation between time and forgetting is far from perfect even when retention is tested over intervals lasting seconds. Importantly, however, such findings by themselves do not rule out the concept of decay. It is still possible that memory traces decay with time, but particularly supportive retrieval environments can counteract the loss. In the Turvey et al. (1970) study, for instance, moving from a 20-s distractor-filled retention interval to a 15-s interval may have helped the participant discriminate to-be-remembered items from information recalled on prior trials (Nairne, 2002b). Similarly, the emergence of newly recalled items on a second or third recall attempt could simply reflect participants' ability to use recalled items as cues to help them recall new items. The state of the trace could still be degraded at time 2 relative to time 1, but a more supportive retrieval environment at time 2 nets improved recall.

At the same time, recognizing that retention cannot be predicted from the state of the memory trace, without considering the retrieval environment, seriously undermines the theoretical utility of decay. Appealing to decay as the source of forgetting is like appealing to strength as the source of remembering. As Endel Tulving (1983) has argued, memory traces "do not have strength independently of the conditions under which they are actualized" (Tulving, 1983: 240–241). Thus, losing trace features over time may or may not impair retention; it will depend on the particular features that are lost and their compatibility with the retrieval cues present at the time of retention testing (Nairne, 2002a).

### 2.12.5.2 Interference: Trace Degradation

The second, and more popular, interpretive tool used to explain forgetting is *interference.* The concept of interference is multifaceted, having several distinct meanings, but the important common denominator is the occurrence of other mnemonic events. We forget because other events interfere with the storage or recovery of target memories. Unlike decay, the interference perspective assumes that if one could create a mental vacuum – that is, if you could measure the state of a memory trace over time in the absence of other mnemonic events or activities – there would be no decline in the integrity of the trace. Forgetting occurs because other events or activities, particularly ones that are memory-based, happen 'in time.'

There are two ways that interference is thought to operate. First, newly learned material can overwrite, erase, displace, or otherwise degrade an existing memory trace. The details are usually left unspecified, although it is generally assumed that similarity between original and new learning increases the extent of the interfering effect. As noted above, many studies have shown that if the retention interval is held constant, the nature of the activities that occur between study and test importantly determines what and how much is forgotten. In a classic study by Jenkins and Dallenbach (1924), for instance, people recalled more information if they slept through a retention interval than if they remained awake; the assumption here is that sleep protects one from the potentially damaging effects of interpolated interference. Comparable findings occur even for amnesic subjects: After hearing words or stories, if amnesic patients are allowed to spend a retention interval in a dark and quiet room, their subsequent retention is vastly improved relative to an interference control (Cowan et al., 2004).

Moreover, in an interesting parallel to decay, some researchers assume that the damaging effects of interference depend on the passage of time as well. Rather than exerting a negative effect, however, memory traces are assumed to become less vulnerable to the effects of interference with time because of a trace consolidation process. The notion that memory traces consolidate is widely accepted by neuroscientists, partly because retrograde amnesia, the loss of memories formed prior to brain damage, shows a distinct temporal gradient (Ribot, 1881). A blow to the head is more likely to lead to the loss of recently formed memories than to the loss of memories from the more distant past. Presumably this pattern occurs because the older traces have consolidated and, as a consequence, are less susceptible to interference. As Wixted (2004a,b) has recently observed, exactly the same reasoning can be applied to general mnemonic principles such as Jost's law: Given two traces of the same strength, but of different ages, retention of the older one will fall off less rapidly in a given length of time, presumably because the older trace has sufficiently consolidated.

In the laboratory, however, the concept of consolidation has a more checkered past. In fact, it has been largely rejected by memory theorists for decades because laboratory-based experiments typically fail to show convincing temporal gradients. It is possible to obtain robust retroactive interference – the term used to describe interference arising from events occurring after the target memory is established – when the interfering event occurs days or even weeks after the original encoding, a period far exceeding any reasonable consolidation time. Moreover, the interference that is obtained after a short delay, when consolidation processes are presumably active, is usually comparable in size to the interference obtained after lengthy delays (see Wickelgren, 1977, for a review).

In fairness to consolidation theory, though, the fact that robust retroactive interference occurs after a long delay does not rule out a consolidation process, for much the same reason that retention after a lengthy delay does not rule out a decay process. As discussed in the next section, interpolated learning can easily decrease the accessibility of a fully formed memory trace by impairing the diagnostic value of an associated retrieval cue. Moreover, Wixted (2004b) has recently challenged the accepted dogma concerning temporal gradients, arguing that traditional retroactive interference designs introduce methodological problems that cloud interpretation. Also, some clinical cases indicate that consolidation may last a relatively long time (Dudai, 2004).

Still, it is important to recognize that consolidation, even if empirically verified, can never stand as a completely adequate account of forgetting (see also Meeter and Murre, 2004). Consolidation theory, like decay theory, essentially reduces to a set of claims about how the integrity of a memory trace changes with the passage of time. As noted, memory traces do not have retention strength outside of the conditions under which they are accessed. For any given trace, degraded or otherwise, there are presumably retrieval conditions that will promote or hinder successful retrieval. To explain forgetting or retention adequately, one needs to consider the state of the memory trace as well as the conditions present at the time retrieval is attempted (Tulving, 1983).

### 2.12.5.3 Interference: Cue Impairment

We mentioned earlier that interference is thought to operate in two ways. The first, just discussed, is the degrading effect that new learning can have on the integrity of an existing trace. The second route places the locus of interference not in the trace itself, but in its eliciting retrieval cue. Psychologists generally assume that remembering is cue-driven. Memories are not thought to arise spontaneously; instead, they are activated by the presence of associated retrieval cues. For decades, the empirical paradigm of choice among researchers was paired-associate learning in which participants are asked to associate target words (e.g., 'town') with cue words (e.g., 'cart'). The advantage of paired-associate learning is that it allows the experimenter to test the integrity of a specific memory by cuing the participant with its associated retrieval cue. The ability to reproduce the target word in the presence of its linked cue is used as the index of retention. When people fail to produce the appropriate response, given the presence of the retrieval cue, then obviously forgetting has occurred.

Once again, forgetting in such a context could occur because the integrity of the target memory has been degraded, either through a decay process or as a by-product of subsequent activity. However, it is also possible that the cue–target association is impaired, leaving the integrity of the target trace intact. In such a case, forgetting occurs because the retrieval cue is unable to elicit or reproduce a previously associated target memory. There are two reasons why the effectiveness of a retrieval cue can become impaired. First, as suggested by early interference theorists (e.g., Melton and Irwin, 1940; McGeoch and Irion, 1952), subsequent activity might lead to 'unlearning' of the cue–target association. Suppose, for example, that after learning an association between 'cart' and 'town', the cue 'cart' is subsequently associated with other targets (e.g., 'block' or 'train'). During this relearning phase, 'cart' occurs in the absence of 'town' and, therefore, the 'cart–town' association extinguishes, much like the process of extinction in Pavlovian conditioning (Pavlov, 1927).

The second and more commonly accepted mechanism for cue impairment is target competition. Even in the absence of unlearning, if a retrieval cue becomes linked to several targets, its ability to elicit any one of those targets lessens. So, if 'cart' is associated initially with 'town,' but then is later paired with 'block' or 'train,' the probability that 'town' will be produced with 'cart' on demand declines (see **Figure 3**). This characteristic of retrieval cues is known by several names, including *response competition, cue distinctiveness,* the *fan effect* (where 'fan' refers to the number of associated target responses), and *cue overload.* Historically the term 'response competition' was used in conjunction with 'unlearning' to form the two 'factors' of the famous two-factor theory of forgetting (McGeoch, 1942; Postman, 1961). Currently, the more popular moniker is *cue overload*, for reasons that will be discussed momentarily.

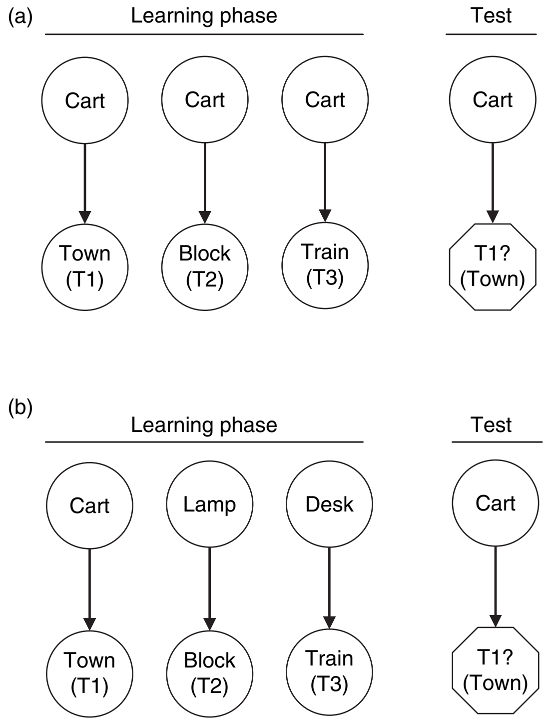


**Figure 3** Illustration of a cue overload situation. In (a) the retrieval cue is linked with several targets, whereas in (b) it is associated only with one target. The predictive value of the cue in situation (a) is lower than in (b) due to cue overload.

The basic phenomenon of cue overload is well supported empirically. For example, as the number of study items from a particular category increases, the category name becomes a less effective cue for eliciting any one item in particular (Tulving and Pearlstone, 1966; Roediger, 1973). Cue overload explains the list length effect as well: recall of any given item from a memory list declines as the length of the list increases. The list length effect occurs, presumably, because people use some representation of the list itself as a cue and it becomes 'overloaded' (i.e., less diagnostic of any particular item) as the number of items subsumed under the list cue increases (Watkins and Watkins, 1975). More directly, it is well established that increasing the number of associated responses to a given target – that is, increasing the cue's associative 'fan' – slows down people's ability to verify any particular cue–target pairing (Anderson, 1974; Anderson and Reder, 1999).

*Cue overload* is the preferred term partly because the locus of interference is believed to lie primarily in the target selection phase rather than in competition among already selected responses. Although this distinction may seem somewhat arbitrary, or at least model-specific, its roots lie in classic work by

Barnes and Underwood (1959) on the modified modified free recall test (MMFR). In an MMFR test, people are asked to recall any or all response terms that have been associated with a cue. There is no requirement to recall a specific response term which, in turn, presumably eliminates any response competition (because any and all responses can be produced). Significant interference is still obtained in the MMFR test – that is, one's ability to recall 'town' to 'cart' remains impaired if other responses have been associated with the cue – and this fact was used by interference theorists to support the concept of unlearning (Postman, 1961). Modern theorists rarely invoke unlearning *per se*, choosing to argue instead that new associations essentially block or impair access to old ones during the target selection phase, or that the recall of one item leads to inhibition or suppression of the other (see Anderson and Neely, 1996, for a review).

Ascribing interference effects to cue impairment – specifically, the ability of a cue to produce a specific target – has considerable advantages. For example, it enables the theorist to explain both retroactive and proactive interference with a single mechanism. As discussed earlier, retroactive interference occurs when newly learned material acts retroactively to impair earlier learning; proactive interference occurs when information learned at time 1 interferes with the ability to access information learned at time 2 (see **Figure 4**). Underwood (1957) provided convincing evidence that much of what is forgotten in standard verbal learning experiments can actually be attributed to proactive interference (i.e., prior learning). **Figure 5**, which is based on data compiled originally by Underwood, shows proportion correct recall of a serial list, tested after an unfilled 24-h interval, as a function of the number of lists learned previously in the experimental context. When the critical list is the only list learned, about 80% of the material will be retained after 24 h; as the potential for proactive interference increases – that is, as the number of prior lists learned increases – delayed retention drops precipitously.

The robust nature of proactive interference is troubling for most of the forgetting mechanisms we have discussed. Why should learning 'cart–town' at time 1 impair one's ability to recover 'cart–block' learned at time 2? Certainly neither decay, nor overwriting, nor unlearning can explain the phenomenon because each is ascribed to things that happen after the point of acquisition. Significant proactive interference is found on an MMFR test as well (Koppenaal, 1963),

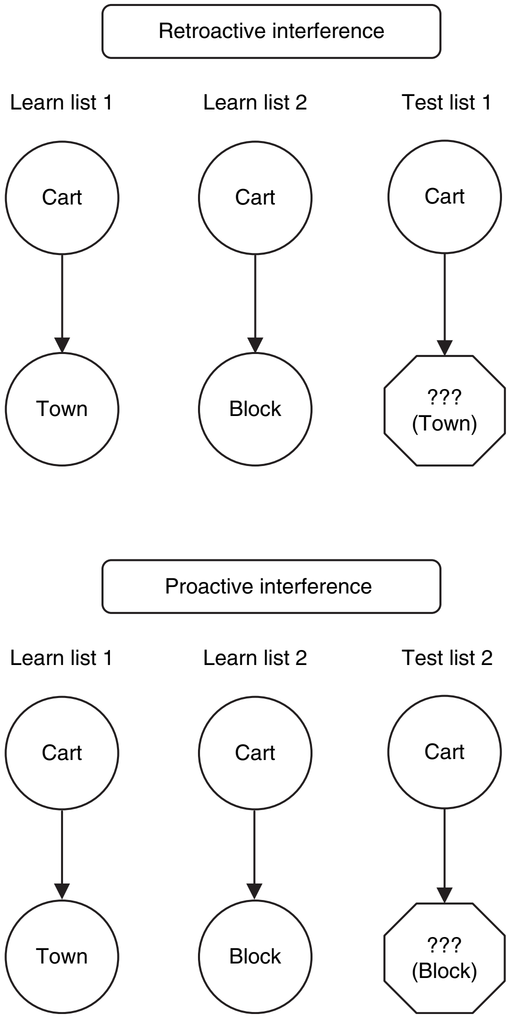


**Figure 4** Representation of experimental settings revealing retroactive interference and proactive interference.

which rules out historical versions of response competition. The only viable forgetting mechanism is cue overload: As the number of targets associated with a cue increases, the ability of the cue to access any particular target declines. Note there is nothing about the order of acquisition that is inherent in the concept of cue overload, although the availability of particular cue–target associations does change in complex ways with time and testing method (see Postman and Underwood, 1973).

### 2.12.5.4 Cue Availability

In addition to interference from events that happen in time, forgetting can also arise from altered stimulus conditions, that is, when "the stimuli necessary to

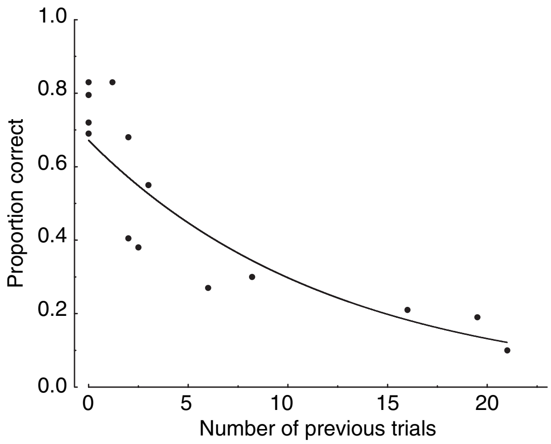


**Figure 5** Proportion of correct responses plotted as a function of the number of previous trials. Data were collected from 14 different studies. After Underwood BJ (1957) Interference and forgetting. *Psychol. Rev.* 64: 49–60.

elicit the originally learned acts are not effectively present" (McGeoch, 1942: 501). Endel Tulving (1974) coined the term *cue-dependent forgetting* to describe the situation. Put simply, if you have learned to associate the target 'town' with the retrieval cue 'cart,' then in the absence of 'cart' you are unlikely to remember 'town.' In this case, there is no degradation or impairment of the target trace, nor any impairment in the cue-target association: We forget simply because we lack the right retrieval cue.

Cue-dependent forgetting helps to explain why memories that seem to have been lost can reappear at a later time. To use the terminology of Tulving and Pearlstone (1966), information can be 'available' in memory, in the sense that the encoded information remains intact somewhere in the memory system, but not 'accessible.' Accessibility requires an appropriate retrieval cue which may be absent at time 1 but may reappear at time 2. Of course, the fact that forgetting proceeds in such a regular fashion, with such a characteristic retention function, suggests that the appearance of retrieval cues may be time-locked. Indeed, psychologists have used the concept of context, which is assumed to change systematically over time, to explain the regularity of forgetting. During presentation, information becomes associated with the context which then changes in accordance with the flow of normal activities (see Estes, 1955; Mensink and Raaijmakers, 1988; Brown et al., 2000, for some specific theories on how context changes). (Note that the examples discussed so far involve external cues (e.g., presenting a cue previously associated with a target), but cue-dependent forgetting can also be demonstrated with internal cues (e.g., mood state; Bower, 1981). In this case, an internal stimulus (such as a mood state) acts as the functional retrieval cue.)

Accepting that remembering (and forgetting) is cue-dependent encourages us to specify the conditions that determine (1) when relevant retrieval cues will be available and (2) the effectiveness of those cues when present. Psychologists have spent decades investigating the second point and have reached consensus that retrieval cues are effective to the extent that they 'match' the contents of the original encoding. The encoding specificity principle, first articulated by Tulving and Thomson (1973), states that retrieval cues will be effective in eliciting targets if and only if the information about them and their relation to the to-be-remembered target is stored at the time of encoding. Thus, the conditions of encoding will uniquely determine whether any given cue will be effective in recovering a prior target episode. Retrieval cues will work if and only if they match, and consequently are a part of, the original encoding complex.

The encoding specificity principle asserts that preexisting associations between cues and targets, such as the semantic relationship between 'bloom' and 'flower,' cannot be used *a priori* to predict the effectiveness of one cue for another. This runs counter to intuition because one would normally expect a strong associate to elicit the target naturally, allowing it to be confirmed easily as a member of the study list. Yet, Tulving and Thomson (1973) showed that a weak associate to the target 'flower,' such as 'fruit,' can actually be a better cue than the strong associate when conditions promote the encoding of the weak associate during study. It follows as well that retention will depend on the match between the retrieval cue and the target memory, as encoded, rather than on the cue and target as originally presented. Presenting the same nominal cue at test will not necessarily be effective. It will depend on whether the participant interprets the retrieval cue at test in the same way that he or she interpreted the cue during the original encoding.

Virtually all psychologists recognize the importance of matching the encoding and retrieval environments, to assure the availability of an appropriate cue, but some have questioned the role of the match *per se*. For example, Nairne (2001, 2002a) has argued that it is the diagnostic value of the retrieval cue that really matters. Rather than a passive matching process, retrieval is better characterized as an active selection process wherein cues are used to pick and choose from among viable retrieval candidates. Matching the retrieval cue with the original encoding context, as encoded, can be expected to increase the diagnostic value of the cue in most situations, but it is easy to conceive of situations in which increasing the match will not improve retention, or perhaps even lower it. For example, if features are added to the cue that match the target exactly, but also match additional non-target items, then the difficulty of the target selection process can increase and performance decline.

The situation is somewhat akin to the relationship between stimulus intensity and the perception of brightness. It is generally the case that increasing the intensity of a light source makes things look brighter, but what mainly determines brightness perception is relative intensity information. It is the number of photons falling in a given spot relative to the number falling in surrounding spots that determines how bright the central spot appears. In fact, it is possible to increase the absolute light intensity falling on the spot and make it look darker (as long as light intensity in the surround is greater still). In discussing brightness perception, it is misleading to focus on light intensity *per se* because our visual system tends to throw away absolute information in favor of relative comparisons. Similarly, for retrieval, it is misleading to focus on the absolute match between a retrieval cue and an encoded target when it is actually the diagnostic value of the cue – the relative match – that really matters (see Nairne, 2002a).

### 2.12.5.5 Retrieval-Induced Inhibition

One interesting feature of the forgetting mechanisms that we have discussed so far is their passive nature. Things happen to the memory trace which yields it less recoverable: It decays, it is degraded by subsequent events, the cue–target association is extinguished by new learning, or the memory target exists in an unrecoverable state because an appropriate retrieval cue is lacking. Yet from an adaptive perspective, it seems likely that our memory systems may have evolved active mechanisms to inhibit or suppress information in specific situations in which that information is not needed. Inhibitory processes certainly play an important role in the nervous system, particularly in neural communication, so it is not a stretch to assume that inhibition is vital to memory processing as well. We might also assume that the effects of inhibition, when it occurs, must be temporary given the continuously changing nature of our processing goals (MacLeod and Macrae, 2001).

To be clear, in modern memory theory the concept of inhibition is synonymous with suppression. When a memory trace is inhibited, it is not degraded, damaged, or impaired, it is simply rendered temporarily unavailable by an active suppression process. Importantly, suppression of this sort differs from the retrieval blocking produced as a consequence of cue overload. In cue overload, competition among viable targets produces a 'winner' and unselected targets suffer as a consequence, but there is no need to assume suppression of the 'losers.' Likewise, recall is often claimed to have inhibitory properties (Roediger, 1974, 1978) because the act of recalling one item can lower the probability that other items will also be recalled; however, this kind of 'output interference' is generally assumed to result from biased sampling rather than from suppression. Once an item is recalled, the probability that it will be sampled again increases (it is primed) which, in turn, lowers the probability that other targets will be sampled. Note that inhibition might well occur as a by-product of cue overload, or biased sampling in recall, but it is not needed to produce forgetting in these instances.

As it turns out, the best evidence for inhibition comes from an empirical procedure known as the *retrieval practice paradigm* (Anderson et al., 1994). Here, people first learn lists of category-exemplar pairs (e.g., 'fruit–banana,' 'drink–scotch') and are then asked to practice retrieval of half of the exemplars from half of the list categories. Practice takes the form of completing stem-recall tests ('fruit-or____?') which people are required to complete several times. Last, after a short delay, a final category cued recall test is given for all of the exemplars (see **Figure 6**). There are two main findings of note: First, recall of the practiced exemplars is superior to that of the unpracticed exemplars; second, recall of the unpracticed exemplars from the practiced categories is impaired relative to exemplars from the unpracticed categories. Thus, practicing the recall of 'fruit–orange' impairs recall of the unpracticed exemplar 'fruit–banana,' below the baseline recall level for exemplars from the unpracticed categories. This impairment is known as *retrieval-induced forgetting* and is thought to accrue from an active inhibitory process.

Of course, there are other interpretations of these findings. For instance, one could appeal simply to retrieval blocking. Practicing 'fruit–orange' increases the strength of the cue–target association which, in turn, should bias the system to sample 'orange' in the

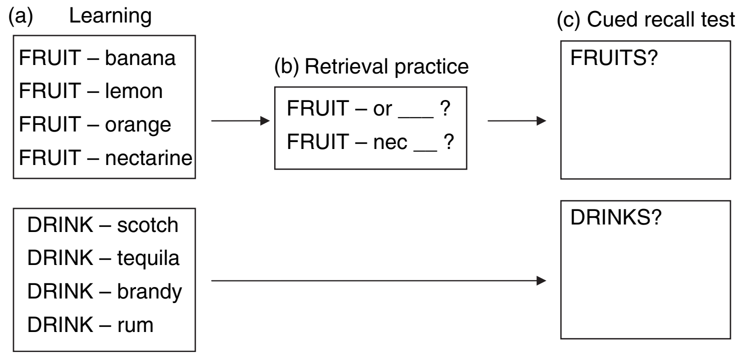


**Figure 6** A simplified version of the retrieval practice paradigm. (a) Elements of two different categories are learned. (b) Half of the elements from one category are subject to a retrieval practice phase–cued word stem completion. (c) After a distractor period, participants respond to a cued recall test with the category name; participants are required to recall all the information learned in (a).

presence of 'fruit' to the exclusion of other exemplars. What supports the presence of active inhibition is the finding that the impairment is cue independent, that is, recall of 'orange' is impaired even when queried with cues unrelated to the category cue 'fruit' (see Anderson, 2003). In retrieval blocking, the impairment results from competition among targets elicited or matched by a given cue which, in turn, should lessen if 'orange' is cued by a target that is less overloaded. As a result, the retrieval practice paradigm seems to create a target that is truly suppressed, leading to impairment regardless of how the target is queried at the point of test.

As noted earlier, the idea that our memory systems may have developed mechanisms for actively suppressing information makes considerable adaptive sense. For any given constellation of retrieval cues, there is likely to be a wide array of potentially recallable responses, so it is in our interest to reduce irrelevant clutter. A telephone, for example, potentially elicits dozens of numbers to call, but we focus on the number at hand and push the remaining numbers out of mind (Levy and Anderson, 2002). A similar task faces us in perception: We must focus our attention on relevant portions of the sensory/perceptual message and block out the irrelevant ones. In memory, as in perception, it is adaptive to exercise cognitive control in our efforts to prioritize functioning. Inhibition – i.e., active suppression – is undoubtedly a useful weapon in the arsenal of cognitive control.

### 2.12.5.6 Motivated Forgetting

Proposals about inhibitory control in memory retrieval lead one naturally to the concept of repression, Freud's proposed defense mechanism (Freud, 1915). Although exactly what Freud meant by repression is open to some interpretation (Boag, 2006), it is generally conceived as a mechanism for preventing anxiety-inducing memories, usually traumatic, from entering the sphere of conscious awareness (Gleaves et al., 2004). Motivated forgetting of this sort seems adaptive: Unpleasant or traumatic memories can interfere with normal functioning, and the associated stress reactions can lead to long-term health consequences as well.

Adaptive speculations aside, is there solid empirical evidence for repression? Unfortunately, most of the relevant data are anecdotal. For obvious reasons, laboratory-based investigations of trauma-induced memory suppression are virtually impossible to conduct. The case for repression continues to rest largely on the many reports of trauma-based amnesia, and subsequent recovery during therapy, that have been obtained in clinical settings. Some relevant survey data and/or clinical cases exist as well, during which people with known histories of sexual abuse have reported periods of amnesia for their abuse (e.g., Williams, 1994; Schooler et al., 1997). However, perhaps not surprisingly, few in the scientific community find these data to be particularly convincing (e.g., Kihlstrom, 2004).

The clinical data are controversial for several reasons. First, in therapeutic settings it is often difficult to verify whether the traumatic event actually occurred or occurred in the form revealed by the recovered memory. Therapists usually do not seek independent corroboration of their clients' reports, again largely for ethical reasons (Shobe and Kihlstrom, 2002). Second, many psychologists believe that therapist–client interactions are particularly prone to the inducement of false memories, perhaps because prior abuse is believed by many to be an important determinant of psychological problems. This is not to imply that false recovered memories are purposely implanted by the therapist, but they can occur as an unintentional by-product (e.g., Porter et al., 1999).

Finally, even if the traumatic event did occur, and the recovered memory is accurate in all details, this does not mean that an active repression process has produced the forgetting. As documented in this chapter, there are many reasons why people forget, and normal forgetting processes could easily account for many, if not all, of the verifiable cases of repressed memory. Just because a memory is traumatic does not mean that it is insensitive to decay, interference, or cue-dependent forgetting. In fact, given that many clinically relevant instances of abuse are thought to occur during childhood, or are accompanied by considerable emotional distress, it is perhaps not surprising that relevant retrieval cues are sometimes lacking at later points in time. Inhibitory mnemonic processes probably do exist, as evidence from the retrieval practice paradigm has shown, but whether there are special inhibitory processes (i.e., repression) that apply when memories are traumatic or emotionally tinged remains speculative at best.

## 2.12.6 Conclusions

Forgetting occurs when we fail to recover information that has been experienced previously. As noted initially, the common tendency is to label forgetting as a nuisance (or worse), but the process itself is actually quite adaptive. Imagine entering the parking garage after work and simultaneously recovering the locations of all of your previous parking spots. In his famous case study of the Russian journalist S., who was plagued by an inability to forget, Luria (1968) describes the torment S. experienced daily. S. had great trouble reading books, for example, because words and phrases so flooded his mind with previous associations that he was unable to concentrate. To avoid a truly cluttered mind, it is reasonable to assume that forgetting is a design feature of memory, that is, a cognitive capability that was selected for and maintained during the evolutionary history of our species.

Given the role that forgetting plays in normal functioning, it is reasonable to assume as well that there are many routes to forgetting. In the bulk of this chapter, we discussed a variety of forgetting mechanisms, everything from decay to interference to inhibition (summarized in **Table 1**). Each mechanism carries some weight of evidence and continues

**Table 1** Summary of the mechanisms of forgetting presented in the chapter

| *Mechanism* | *Source* | *Process* | *Effect* |
|---|---|---|---|
| Decay | Time | Autonomous process | Traces, or trace features, are permanently lost with time |
| Consolidation | Time | Autonomous process | Memories become more resistant to forgetting with time |
| Interference | Other acquired information | Trace degradation (Retroactive interference) | Newly acquired information damages the integrity of existing memory traces (e.g., overwriting) |
| | | Cue impairment (Retroactive interference) (Proactive interference) | Other acquired information impairs the ability of a cue to produce a specific target due to the unlearning of preexisting associations between the cue and the target, or to target competition resulting from the association of the same cue with several targets (cue overload) |
| Cue availability | Altered stimulus conditions | Absence of an effective retrieval cue | The cue needed to elicit the originally learned information is not available |
| Retrieval-induced inhibition | Retrieval of other information | Active inhibition process | Temporary inhibition of information in situations in which it is not needed or when it competes with other target memories |
| Motivated forgetting | Repression | Active repression | Prevents anxiety-inducing memories, usually traumatic, from entering the sphere of conscious awareness |

to have many advocates. It would be improper to conclude that any one of these mechanisms is 'the' forgetting mechanism because different situations will undoubtedly demand different forgetting solutions. In some circumstances, important information needs to be suppressed temporarily; in others it may be in our interest to forget things permanently (or nearly so).

Whatever the mechanism, however, it does remain a challenge for memory theorists to explain the regularity of the forgetting function. As documented earlier, the function relating recovery to time is very regular in form (see **Figure 1**). Attributing forgetting to interference from subsequent events, or to the action of cue overload, does little to explain why the forgetting curve is consistently negatively accelerated. Forgetting may indeed be cue-dependent, but then what determines the availability of appropriate cues? As the forgetting curve informs, forgetting is by no means a random occurrence.

Lastly, it is worth noting that forgetting can never be measured directly: We can only measure what has been 'remembered,' at a particular time, given a particular context. And, as we have described, what appears to have been forgotten may, in fact, turn out to be recoverable at another time or in a different context. To the extent that our memory systems are designed to use the past, in combination with the present, to generate adaptive behavior, then the variability of memory is hardly surprising. Stored information should be retrieved when it is necessary and not otherwise. In this sense it is a mistake to speculate about the ultimate 'cause' of forgetting, or to consider forgetting as a breakdown in normal functioning, because our memory systems are not designed to recover stored information at will: Recovery will depend on the situation and, more importantly, on the particular adaptive problem at hand.

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## References


Altmann EM and Gray WD (2002) Forgetting to remember: The functional relationship of decay and interference. *Psychol. Sci.* 13: 27–33.

Anderson JR (1974) Retrieval of propositional information from long-term memory. *Cogn. Psychol.* 6: 451–474.

Anderson JR and Reder LM (1999) The fan effect: New results and new theories. *J. Exp. Psychol. Gen.* 128: 186–197.

Anderson JR and Schooler LJ (1991) Reflections of the environment in memory. *Psychol. Sci.* 2: 396–408.

Anderson MC (2003) Rethinking interference theory: Executive control and the mechanisms of forgetting. *J. Mem. Lang.* 49: 415–445.

Anderson MC and Neely JH (1996) Interference and inhibition in memory retrieval. In: Bjork EL and Bjork RA (eds.) *Memory: Handbook of Perception and Cognition*, pp. 237–313. New York: Academic Press.

Anderson MC, Bjork RA, and Bjork EL (1994) Remembering can cause forgetting: Retrieval dynamics in long-term memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 1063–1087.

Baddeley AD (1976) *The Psychology of Memory*. New York: Basic Books.

Baddeley AD (2000) The episodic buffer: A new component of working memory? *Trends Cogn. Sci.* 4: 417–423.

Baddeley AD and Hitch GJ (1974) Working memory. In: Bower GA (ed.) *Recent Advances in Learning and Motivation*, vol. 8, pp. 47–89. New York: Academic Press.

Bahrick HP (1984) Semantic memory content in permastore: Fifty years of memory for Spanish learned in school. *J. Exp. Psychol. Gen.* 113: 1–29.

Bahrick HP (2000) Long-term maintenance of knowledge. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 347–362. New York NY: Oxford University Press.

Ballard PB (1913) Obliviscence and reminiscence. *Br. J. Psychol. Monogr. Suppl.* 1: 1–82.

Barnes JM and Underwood BJ (1959) "Fate" of first-list associations in transfer theory. *J. Exp. Psychol.* 58: 97–105.

Bartlett FC (1932) *Remembering: A Study in Experimental and Social Psychology*. New York: Cambridge University Press.

Bjork EL and Bjork RA (1988) On the adaptive aspects of retrieval failure in autobiographical memory. In: Gruneberg MM, Morris PE, and Sykes RN (eds.) *Practical Aspects of Memory: Current Research and Issues,* vol. 1, pp. 283–288. London: Wiley.

Bjork EL and Bjork RA (1996) Continuing influences of to-be-forgotten information. *Conscious. Cogn.* 5: 176–196.

Bjork RA and Bjork EL (1992) A new theory of disuse and an old theory of stimulus fluctuation. In: Healy AF, Kosslyn SM, and Shiffrin RM (eds.) *From Learning Processes to Cognitive Processes: Essays in Honor of William K. Estes,* vol. 2, pp. 35–67. Hillsdale, NJ: Erlbaum.

Bjork RA and Whitten WB (1974) Recency-sensitive retrieval processes in long-term free recall. *Cogn. Psychol.* 6: 173–189.

Boag S (2006) Freudian repression, the common view, and pathological science. *Rev. Gen. Psychol.* 10: 74–86.

Bogartz RS (1990) Learning-forgetting rate independence defined by forgetting function parameters or forgetting function form: Reply to Loftus and Bamber and to Wixted. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 936–945.

Bower GH (1981) Mood and memory. *Am. Psychol.* 36: 129–148.

Bower GH and Forgas JP (2000) Affect, memory, and social cognition. In: Forgas J, Eick K, and Bower GH (eds.) *Cognition and Emotion*, pp. 87–168. New York: Oxford University Press.

Brown GD, Preece T, and Hulme C (2000) Oscillator-based memory for serial order. *Psychol. Rev.* 107: 127–181.

Chechile RA (1987) Trace susceptibility theory. *J. Exp. Psychol. Gen.* 116: 203–222.

Chechile RA (2006) Memory hazard functions: A vehicle for theory development and test. *Psychol. Rev.* 113: 31–56.

Christensen H, Kopelman M, Stanhope N, Lorentz L, and Owen P (1998) Rates of forgetting in Alzheimer dementia. *Neuropsychologia* 36: 547–557.

Cowan N, Saults J, and Nugent LD (1997) The role of absolute and relative amounts of time in forgetting within immediate memory: The case of tone-pitch comparisons. *Psychon. Bull. Rev.* 4: 393–397.
Cowan N, Saults S, and Nugent L (2001) The ravages of absolute and relative amounts of time on memory. In: Roediger HL III, Nairne JS, Neath I, and Surprenant AM (eds.) *The Nature of Remembering: Essays in Honor of Robert G. Crowder*, pp. 315–330. Washington, DC: American Psychological Association.
Cowan N, Beschin N, and Della Sala S (2004) Verbal recall in amnesiacs under conditions of diminished retroactive interference. *Brain* 127: 825–834.
Dudai Y (2004) The neurobiology of consolidations, or, how stable is the engram. *Annu. Rev. Psychol.* 55: 51–86.
Ebbinghaus H (1885/1964) *Memory: A Contribution to Experimental Psychology*. Oxford: Dover.
Estes W (1955) Statistical theory of spontaneous recovery and regression. *Psychol. Rev.* 62: 145–154.
Freud S (1915) *Repression*, vol. XIV. London: Hogarth.
Galton F (1879) Psychometric experiments. *Brain* 2: 148–162.
Gleaves DH, Smith SM, Butler LD, and Spiegel D (2004) False and recovered memories in the laboratory and clinic: A review of experimental and clinical evidence. *Clin. Psychol. Sci. Pract.* 11: 3–28.
Greene RL (1996) The influence of experimental design: The example of the Brown-Peterson paradigm. *Can. J. Exp. Psychol.* 50: 240–242.
Jenkins J and Dallenbach K (1924) Obliviscence during sleep and waking. *Am. J. Psychol.* 35: 605–612.
Jost A (1897) Die Assoziationsfestigkeit in ihrer Abhängigkeit von der Verteilung der Wiederholungen [The strength of associations in their dependence on the distribution of repetitions]. *Z. Psychol. Physiol. Sinnesorgane* 14: 436–472.
Kareev Y (2000) Seven (indeed, plus or minus two) and the detection of correlations. *Psychol. Rev.* 107: 397–403.
Keppel G (1968) Retroactive and proactive inhibition. In: Dixon TR and Horton DL (eds.) *Verbal Behavior and General Behavior Theory*, pp. 172–213. Englewood Cliffs, NJ: Prentice-Hall.
Kihlstrom JF (2004) An unbalanced balancing act: Blocked, recovered, and false memories in the laboratory and clinic. *Clin. Psychol. Sci. Pract.* 11: 34–41.
Koppenaal R (1963) Time changes in strength of A-B, A-C lists: Spontaneous recovery? *J. Verb. Learn. Verb. Behav.* 2: 310–319.
Lee MD (2004) A Bayesian analysis of retention functions. *J. Math. Psychol.* 48: 310–321.
Levy BJ and Anderson MC (2002) Inhibitory processes and the control of memory retrieval. *Trends Cogn. Sci.* 6: 299–305.
Loftus GR and Bamber D (1990) Learning-forgetting independence, unidimensional memory models, and feature models: Comment on Bogartz (1990). *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 916–926.
Luria AR (1968) *The Mind of a Mnemonist*. New York: Basic Books.
MacDonald SW, Stigsdotter-Neely A, Derwinger A, and Backman L (2006) Rate of acquisition, adult age, and basic cognitive abilities predict forgetting: New views on a classic problem. *J. Exp. Psychol. Gen.* 135: 368–390.
MacLeod MD and Macrae C (2001) Gone but not forgotten: The transient nature of retrieval-induced forgetting. *Psychol. Sci.* 12: 148–152.
McBride DM and Dosher BA (1999) Forgetting rates are comparable in conscious and automatic memory: A process-dissociation study. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 583–607.
McGeoch JA (1932) Forgetting and the law of disuse. *Psychol. Rev.* 39: 352–370.
McGeoch JA (1942) *The Psychology of Human Learning*. New York: Longmans and Green.
McGeoch JA and Irion AL (1952) *The Psychology of Human Learning*, 2nd edn. New York: Longmans and Green.
Meeter M and Murre JM (2004) Consolidation of long-term memory: Evidence and alternatives. *Psychol. Bull.* 130: 843–857.
Melton AW and Irwin JM (1940) The influence of degree of interpolated learning on retroactive inhibition and the overt transfer of specific responses. *Am. J. Psychol.* 53: 173–203.
Mensink G-J and Raaijmakers JG (1988) A model for interference and forgetting. *Psychol. Rev.* 95: 434–455.
Müller GE and Pilzecker A (1900) Experimentelle Beiträge zur Lehre vom Gedächtnis [Experimental contributions to the science of memory]. *Z. Psychol.* 1(supplement): 1–300.
Nairne JS (2001) A functional analysis of primary memory. In: Roediger HL III, Nairne JS, Neath I, and Surprenant AM (eds.) *The Nature of Remembering: Essays in Honor of Robert G. Crowder*, pp. 283–296. Washington, DC: American Psychological Association.
Nairne JS (2002a) The myth of the encoding-retrieval match. *Memory* 10: 389–395.
Nairne JS (2002b) Remembering over the short-term: The case against the standard model. *Annu. Rev. Psychol.* 53: 53–81.
Osgood CE (1953) *Method and Theory in Experimental Psychology*. New York: Oxford University Press.
Page MP and Norris D (1998) The primacy model: A new model of immediate serial recall. *Psychol. Rev.* 105: 761–781.
Pavlov IP (1927) *Conditioned Reflexes*. London: Oxford University Press.
Pitt MA, Myung IJ, and Zhang S (2002) Toward a method of selecting among computational models of cognition. *Psychol. Rev.* 109: 472–491.
Porter S, Yuille JC, and Lehman DR (1999) The nature of real, implanted, and fabricated memories for emotional childhood events: Implications for the recovered memory debate. *Law Hum. Behav.* 23: 517–537.
Postman L (1961) The present status of interference theory. In: Cofer CN and Musgrave BS (eds.) *Verbal Learning and Verbal Behavior*, pp. 152–196. New York: McGraw-Hill.
Postman L and Underwood BJ (1973) Critical issues in interference theory. *Mem. Cognit.* 1: 19–40.
Reitman JS (1974) Without surreptitious rehearsal, information in short-term memory decays. *J. Verb. Learn. Verb. Behav.* 13: 365–377.
Ribot T (1881) *Les maladies de la mémoire [Diseases of Memory]*. Paris: Germer Bailliere.
Roberts S and Pashler H (2000) How persuasive is a good fit? A comment on theory testing. *Psychol. Rev.* 107: 358–367.
Roediger HL III (1973) Inhibition in recall from cueing with recall targets. *J. Verb. Learn. Verb. Behav.* 12: 644–657.
Roediger HL III (1974) Inhibiting effects of recall. *Mem. Cognit.* 2: 261–269.
Roediger HL III (1978) Recall as a self-limiting process. *Mem. Cognit.* 6: 54–63.
Roediger HL III and Challis BH (1989) Hypermnesia: Increased recall with repeated tests In: Izawa C (ed.) *Current Issues in Cognitive Processes: The Tulane Floweree Symposium on Cognition*, pp. 175–199. Hillsdale, NJ: Erlbaum.
Roediger HL III, Knight JL, and Kantowitz BH (1977) Inferring decay in short-term memory: The issue of capacity. *Mem. Cognit.* 5: 167–176.
Rubin DC, Hinton S, and Wenzel AE (1999) The precise time course of retention. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 1161–1176.
Rubin DC and Wenzel AE (1996) One hundred years of forgetting: A quantitative description of retention. *Psychol. Rev.* 103: 734–760.

Salthouse TA (1991) *Theoretical Perspectives on Cognitive Aging*. Hillsdale, NJ: Erlbaum.
Schacter DL and Addis DR (2007) The cognitive neuroscience of constructive memory: Remembering the past and imagining the future. *Philos. Trans. R. Soc. B* 362: 773–786.
Schooler LJ and Hertwig R (2005) How forgetting aids heuristic inference. *Psychol. Rev.* 112: 610–628.
Schooler JW, Ambadar Z, and Bendiksen M (1997) A cognitive corroborative case study approach for investigating discovered memories of sexual abuse. In: Read JD and Lindsay DS (eds.) *Recollections of Trauma: Scientific Evidence and Clinical Practice*, pp. 379–387. New York: Plenum Press.
Shobe KK and Kihlstrom JF (2002) Interrogative suggestibility and ''memory work.'' In: Eisen ML, Quas JA, and Goodman GS (eds.) *Memory and Suggestibility in the Forensic Interview*, pp. 309–327. Mahwah, NJ: Erlbaum.
Simon HA (1966) A note on Jost's law and exponential forgetting. *Psychometrika* 31: 505–506.
Slamecka NJ (1985) On comparing rates of forgetting: Comment on Loftus (1985) *J. Exp. Psychol. Learn. Mem. Cogn.* 11: 812–816.
Slamecka NJ and McElree B (1983) Normal forgetting of verbal lists as a function of their degree of learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 9: 384–397.
Suddendorf T and Corballis MC (1997) Mental time travel and the evolution of the human mind. *Genet. Soc. Gen. Psychol. Monogr.* 123: 133–167.
Tulving E (1974) Cue-dependent forgetting. *Am. Sci.* 62: 74–82.
Tulving E (1983) *Elements of Episodic Memory*. New York: Oxford University Press.
Tulving E (2002) Chronesthesia: Conscious awareness of subjective time. In: Stuss DT and Knight RT (eds.) *Principles of Frontal Lobe Function*, pp. 311–325. New York: Oxford University Press.
Tulving E and Pearlstone Z (1966) Availability versus accessibility of information in memory for words. *J. Verb. Learn. Verb. Behav.* 5: 381–391.
Tulving E and Thomson DM (1973) Encoding specificity and retrieval processes in episodic memory. *Psychol. Rev.* 80: 352–373.
Turvey M, Brick P, and Osborn J (1970) Proactive interference in short-term memory as a function of prior-item retention interval. *Q. J. Exp. Psychol.* 22: 142–147.
Underwood BJ (1957) Interference and forgetting. *Psychol. Rev.* 64: 49–60.
Underwood BJ (1964) Degree of learning and the measurement of forgetting. *J. Verb. Learn. Verb. Behav.* 3: 112–129.
Watkins OC and Watkins MJ (1975) Buildup of proactive inhibition as a cue-overload effect. *J. Exp. Psychol. Hum. Learn. Mem.* 1: 442–452.
Waugh NC and Norman DA (1965) Primary memory. *Psychol. Rev.* 72: 89–104.
Wheeler MA (1995) Improvement in recall over time without repeated testing: Spontaneous recovery revisited. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 173–184.
Wickelgren WA (1977) *Learning and Memory*. Englewood Cliffs, NJ: Prentice-Hall.
Williams LM (1994) Recall of childhood trauma: A prospective study of women's memories of child sexual abuse. *J. Consult. Clin. Psychol.* 62: 1167–1176.
Wixted JT (2004a) On common ground: Jost's (1897) law of forgetting and Ribot's (1881) law of retrograde amnesia. *Psychol. Rev.* 111: 864–879.
Wixted JT (2004b) The psychology and neuroscience of forgetting. *Annu. Rev. Psychol.* 55: 235–269.
Wixted JT and Carpenter SK (2007) The Wickelgren power law and the Ebbinghaus savings function. *Psychol. Sci.* 18: 133–134.
Wixted JT and Ebbesen EB (1991) On the form of forgetting. *Psychol. Sci.* 2: 409–415.

# 2.13 Inhibitory Processes

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## 2.13.1 Introduction

### 2.13.1.1 Retrieval Competition

In the course of a day, we encounter a huge number of experiences that we encode and store in our memory. Some of these experiences may be unique and lead to the encoding of very distinct features. Most of the experiences, however, will share certain features with other experiences, thus leading to the encoding of common features in our memory. In his morning lecture, a professor, for instance, may encode many distinct features of each participating student while, for all students, encoding the common feature of participating in this particular course of study. The encoding of this common contextual feature can create a problem for the professor's memory when later asked about the names of the participating students. Typically, the larger the number of students who were present in the lecture, the poorer will be the professor's recall for any one particular name. The reason for this retrieval problem is retrieval competition.

Retrieval competition means that memories that share a common cue – be it a contextual, semantic, or emotional cue – compete for conscious recall once the cue is provided and, as a result, show both reduced recall performance and increased response latencies (**Figure 1(a)**). Corresponding evidence has been provided by a number of studies in quite different experimental paradigms. In single-list paradigms, for instance, memory for target information has been found to decline and to be slowed down when the number of list items increases, which is known as the list-length effect (Watkins, 1975). In multiple-list

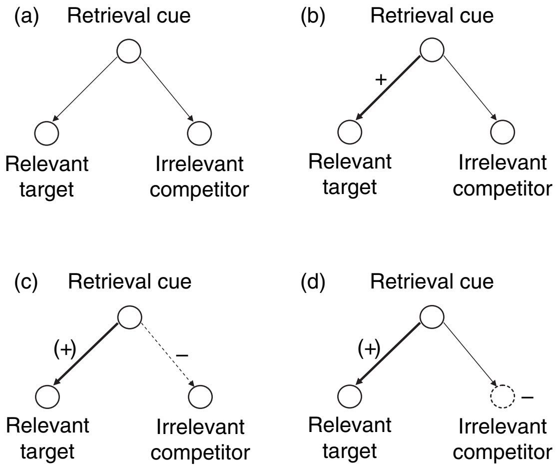


**Figure 1** (a) Retrieval competition. Relevant target and irrelevant competitor material are connected to the same retrieval cue and compete for conscious recall once the cue is provided. For both materials, the competition reduces recall probability and increases response latency. (b) Blocking. Strengthened target information blocks access to nonstrengthened competitor information. Blocking occurs at test when the strengthened material is recalled first and hinders subsequent recall of the nonstrengthened material. Blocking does not affect the competitor's retrieval route and does not affect its memory representation. (c) Route deactivation. Deactivation of the retrieval route between cue and competitor information (with possible simultaneous enhancement of retrieval route between cue and target). Route deactivation takes place at a pretest encoding or a pretest retrieval stage and reduces chances of the retrieval cue to make competitor information recoverable. (d) Item suppression. Deactivation of the memory representation of the competitor information (with possible simultaneous enhancement of retrieval route between cue and target). Item suppression takes place at a pretest encoding or a pretest retrieval stage and reduces chances to recover the competitor information, regardless of which retrieval cue is provided.

paradigms, it has been shown that both the prior and the subsequent encoding of additional lists of items can impair memory for the target list, which is known as proactive and retroactive interference (Müller and Pilzecker, 1900; Underwood, 1957; for a summary, see Crowder, 1976).

Retrieval competition provides a challenge for the goal-directed use of memory. Indeed, in daily life, relevant and irrelevant information often share a common cue. This may be the case for the more relevant and more irrelevant things that occurred to us in the office, the expired and current passwords of our computer, or the past and current address of a friend's home. When trying to recall the relevant or current information, remembering then may fail because the irrelevant or out-of-date information is retrieved. Effective updating should reduce accessibility of the irrelevant memories and simultaneously enhance that of the more relevant information.

It is an old and prominent idea that, in our memory, inhibitory processes operate to serve the function of goal-directed remembering, reducing the accessibility of irrelevant information and enhancing that of the more relevant information. In this chapter, I summarize results from a number of experimental paradigms in which the action of inhibitory processes serving memory's goal-directed use has been suggested. While there is consensus in the literature that inhibitory mechanisms operate to overcome retrieval competition and enhance the processing of relevant information, different conceptions about inhibitory mechanisms exist. In fact, some researchers speak of inhibition whenever a mechanism reduces accessibility of irrelevant information, be it directly or indirectly. Others speak of inhibition only if a mechanism affects the irrelevant information directly, be it through deactivation of the information itself or through deactivation of some of its retrieval routes.

The goal of this chapter is not to discuss which mechanism reflects real inhibition and which does not. Rather, the goal is to indicate which of the suggested mechanisms operate under what conditions. As it turns out, different mechanisms operate in different experimental contexts, providing us with a detailed picture of how reduced accessibility of irrelevant information is achieved in memory. Before reviewing these results, some of the most important conceptions of inhibitory processes suggested in the past decades are outlined. After becoming familiar with these conceptions, I turn to determining which of the inhibitory processes operates in which experimental context.

### 2.13.1.2 Inhibitory Mechanisms

Three primary inhibitory mechanisms have been suggested to serve the goal of effectively separating relevant from irrelevant information and enhancing memory for the first at the expense of the second. The three mechanisms are blocking, route deactivation, and item suppression.

1. Blocking

As described in section 2.13.1.1, when memories share a common cue, they compete for conscious recall once the cue is provided and show reduced recall performance (**Figure 1(a)**). Such retrieval competition has been shown to be strength dependent. That is, if material that is strongly represented in memory and material that is weakly represented share the same retrieval cue, there is a tendency for the stronger material to be recalled first (Rundus, 1973; Raaijmakers and Shiffrin, 1981; Wixted et al., 1997). Thus, if relevant material, like the current computer password, is represented more strongly in memory than irrelevant material, that is, the expired password, the difference can induce a competition bias at test favoring the early recall of the (stronger) relevant information – the current password. By involuntarily sampling the already recalled material repeatedly, this early recall of the relevant information then can block subsequent recall of the (weaker) irrelevant information – the expired password – and make it inaccessible (**Figure 1(b)**). Such blocking of irrelevant information has repeatedly been regarded as an important example of inhibition in human memory (Melton and Irwin, 1940; McGeoch, 1942; Rundus, 1973) and is a core feature of many computational models (Raaijmakers and Shiffrin, 1981; Mensink and Raaijmakers, 1988).

A crucial feature of blocking is that there is no direct effect of inhibition on the irrelevant material itself and no direct effect on the retrieval routes between the irrelevant material and its cue(s). Rather, the inaccessibility of the irrelevant material (the expired password) arises as a by-product of the strengthening of the relevant material (the current password), which, as a result of biased competition, favors recall of the stronger relevant material and blocks recall of the weaker irrelevant material. Because blocking typically operates at test, its effect should be visible in memory tests in which there is the opportunity for strength-dependent retrieval (i.e., in free recall tasks and in cued recall tasks in which more than one item is connected to the cue). In contrast, blocking should play only a minor role, if any, in memory tests in which item-specific probes are provided as retrieval cues, such as recognition tests or implicit memory tests. In all these tests, strength-dependent competition should be greatly reduced or eliminated.

2. Route deactivation

A more direct way to induce inaccessibility of irrelevant material would be to not only strengthen the relevant material but also weaken the retrieval route between the irrelevant information and its cue, so that retrieval of the irrelevant information becomes less effective (Melton and Irwin, 1940; Geiselman et al., 1983; **Figure 1(c)**). Applied to the computer password retrieval problem, this would mean that, rather than blocking retrieval of the expired computer password, an inhibitory mechanism would directly weaken the connection of the expired password's memory representation to the common password cue. Such route deactivation might operate while the new password is encoded, or it might operate after the encoding of the new password, for instance, when retrieving the current computer password. Because the retrieval routes to the irrelevant information would be affected directly, the effect of such a mechanism should be visible in a number of memory tests and should arise not just in free recall tasks but in all forms of cued recall as well. On the other hand, because the representation of the irrelevant material itself would not be affected, only minor, if any, forgetting of the irrelevant information should be observed in recognition tasks.

The strengthening of relevant information creates a difference in relative strength between relevant and irrelevant information and thus can lead to blocking. Route deactivation also creates a difference in relative strength, which may be particularly strong, if not only the retrieval routes for the irrelevant material are reduced but retrieval routes for the relevant material are simultaneously enhanced. Therefore, route deactivation may trigger blocking at test as an additional mechanism, an effect that should be largely restricted to free recall tasks.

3. Item suppression

Blocking and route deactivation reflect mechanisms that, following Tulving and colleagues' terminology (Tulving and Pearlstone, 1966; Tulving and Psotka, 1971; Tulving, 1974), result in loss of retrieval access to inhibited items rather than in loss of the items' availability. A loss in availability would imply that the memory representation of material is affected itself so that memory for the material is impaired regardless of which retrieval cue is provided. It has repeatedly been suggested that inhibitory processes may affect the item representation itself (Postman et al., 1968; Anderson and Spellman, 1995; **Figure 1(d)**). Applied to the computer password retrieval problem, for instance, this would mean that, rather than blocking the expired computer password or reducing its connection to the common password cue, the memory representation of the expired password would directly be suppressed. Such suppression might operate while the new password is encoded, or it might operate after the encoding of the new password, for instance, when retrieving the current computer password. Due to the direct effect on the memory representation of the irrelevant information itself, item suppression would reflect a strong form of inhibition and should be visible over a wide range of memory tests, including recognition tasks and tasks that employ so-called independent probes, that is, probes not used until the test phase of an experiment.

Like route deactivation, a side effect of item suppression is that a difference in relative strength between relevant and irrelevant material is created, particularly if there is simultaneous strengthening of the relevant information. In memory tests that are sensible to strength-dependence effects, this difference can trigger blocking as an additional inhibitory mechanism. In free-recall tasks, item suppression, therefore, may reduce accessibility of irrelevant material very effectively.

In sum, although blocking, route deactivation, and item suppression can all serve the goal of reducing accessibility of irrelevant material and enhancing that of relevant information, the three mechanisms differ in the way the inaccessibility is achieved. In blocking, the inaccessibility arises because of the difference in relative strength between target and competitor information, with early recall of the stronger target information blocking recall of the weaker competitor information; in route deactivation, inaccessibility arises because of the direct deactivation of the retrieval route between the cue and the irrelevant information; and in item suppression, inaccessibility arises because of the direct deactivation of the memory representation of the irrelevant material itself, which, following Tulving's terminology, represents some form of information unavailability.

The difference in how inaccessibility is achieved in the three inhibitory mechanisms has implications for the range of memory tests in which the effects of inhibition can be observed. Blocking represents the weakest form of inhibition. Because it does not affect the irrelevant material directly, its effects should arise only in memory tests that leave sufficient room for strength-dependent retrieval, like free-recall tasks. By directly affecting the retrieval routes to the irrelevant material, route deactivation represents a stronger form of inhibition, the effects of which should be observable in free-recall and cued-recall tasks. Item suppression, finally, represents the strongest form of inhibition that affects the memory representation of the inhibited item itself and thus should create effects across a wide range of memory tests. Also note that route deactivation and item suppression can trigger additional blocking at test, thus creating a situation in which two inhibitory processes may operate in concert.

The next section examines the role of the three suggested inhibitory mechanisms in experimental paradigms that are often assumed to involve inhibition: strength-induced forgetting, retrieval-induced forgetting, directed forgetting, think/no-think impairment, and part-list cuing impairment. At the end of the section, current knowledge about the developmental trajectory of inhibition in the single paradigms is reviewed. In the conclusion, finally, the results are summarized and a taxonomy of the inhibitory paradigms is suggested.

## 2.13.2 Inhibitory Paradigms

### 2.13.2.1 Strength-Induced Forgetting

A simple way to emphasize memory for relevant material is to present the relevant information repeatedly or longer and the less relevant information less often or for a shorter time period. This is common use in textbooks or talks, in which important information is typically repeated in several places, and it is typically employed by students preparing for an exam, when they spend more time on the seemingly relevant material than on the seemingly irrelevant material.

Strengthening the memory representation of relevant information – be it through repeated or longer study – should lead to different memory performance for the relevant and irrelevant information, simply because of the resulting difference in (absolute) memory strength between the two types of information. The effect of strengthening or inhibition that we observe in experiments, however, is often larger than we might expect on the basis of the encoding difference, suggesting that additional processes enhance accessibility of the relevant material and reduce it for irrelevant material. This point has been demonstrated in a number of experimental paradigms, discussed next. In these paradigms, a subset of the material to be learned is strengthened, and its effect on later memory for the strengthened and nonstrengthened material is examined.

#### *2.13.2.1.1 The mixed-list paradigm*

In the mixed-list paradigm, participants are presented a list of items such as unrelated words. Strengthening effects are then examined by providing a longer presentation time for a subset of the material or by presenting a subset of the material repeatedly (e.g., Tulving and Hastie, 1972; **Figure 2**). For instance, half of the items of a list may be shown for 6 s and the other half for 2 s, or half of the items may be shown twice and the other half once. Memory performance for the two types of items is compared with two pure-list baseline conditions in which there is no such partial strengthening and all material is studied in the same way (i.e., all items are studied for 6 s or all items are studied for 2 s). Memory is typically assessed by means of a free-recall test, a cued-recall test, or a recognition test.

On the basis of the encoding difference between strong and weak items, strong items should show better memory than weak items. In particular, strong items in mixed lists should show the same memory performance as strong items in pure lists, and weak items in mixed lists should show the same performance as weak items in pure lists. The general idea of retrieval competition and blocking, as outlined above (in sections 2.13.1.1 and 2.13.1.2), however, suggests otherwise, at least in free-recall tasks. Partial strengthening in the mixed-list paradigm should introduce a competition bias, leading to early recall of the strengthened items, which then may block subsequent recall of the nonstrengthened items. As a result, on average, strong items in mixed lists should show better performance than strong items in pure lists, and weak items in mixed lists should show poorer performance than weak items in pure lists. Such effects should be present in free-recall tasks, but they should be absent in recognition tasks, in which no such competition bias is expected.

Indeed, free-recall experiments have shown that, in mixed lists, strengthened items are better recalled than nonstrengthened ones and that this effect is not only a result of the difference in the items' absolute memory strength but is also attributable to their difference in relative strength. Recall of strong items was consistently found to be higher in mixed lists than in pure lists, and recall of weak items was

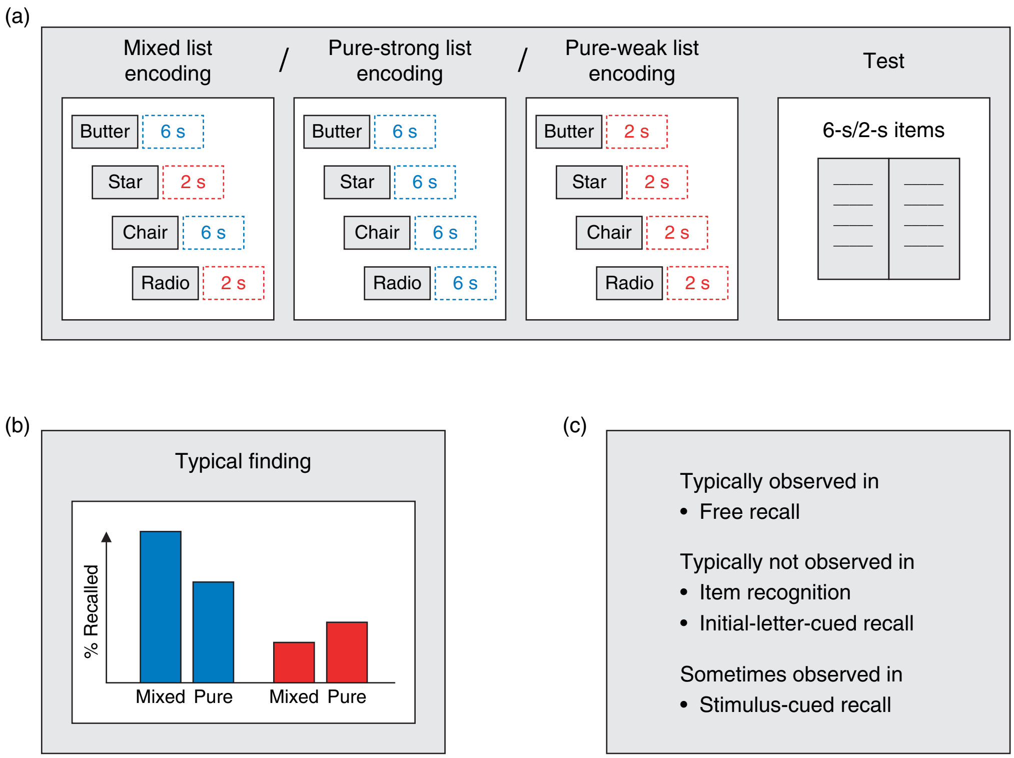


**Figure 2** The list-strength effect. (a) The experimental paradigm. Participants study a mixed list consisting of strong and weak items. Memory for the two types of items on a later test is compared to two baseline conditions: a pure-strong list condition containing strong items only and a pure-weak list condition containing weak items only. Strengthening is accomplished by varying either the exposure time or the number of repetitions of the items to be strengthened. (b) The typical finding. Relatively more strong items are recalled from the mixed list than from the pure-strong list, and relatively fewer weak items are recalled from the mixed list than from the pure-weak list. (c) Memory tests. Examples of memory tests in which the list-strength effect typically arises and in which it typically does not arise.

found to be poorer in mixed lists than in pure lists (Tulving and Hastie, 1972; Ratcliff et al., 1990; see also Malmberg and Shiffrin, 2005). In contrast, such list-strength effects have typically been found to be absent in recognition tasks. Although recognition of strong items was found to be higher than recognition of weak items, performance for the two types of items did not vary with list composition (Ratcliff et al., 1990; Murnane and Shiffrin, 1991; Ratcliff et al., 1992).

A few studies reported reliable recognition effects in the mixed-list paradigm (see Norman, 2002, for item recognition, and Verde and Rotello, 2004, for associative recognition), which were used to draw inferences on whether the effects were caused by changes in recollection or changes in the familiarity of the items. Tulving (1985) distinguished between two bases for judging an item as 'old' on a recognition test: The participant specifically remembers the temporal and/or spatial context in which the item was studied (recollection), or the participant finds the item just familiar (familiarity; for a review, see Yonelinas, 2002). From the studies reporting reliable list-strength effects in recognition, evidence has arisen that the list-strength effect reflects mainly a modulation in recollection but does not affect familiarity.

A number of studies examined list-strength effects in cued recall. In paired-associate learning with stimulus-cued recall tests, a mixed picture arose with reliable effects in some experiments and nonreliable ones in others (Ratcliff et al., 1990). List-strength effects were also examined when categorized lists were studied. In this case, each category studied was a mixed category, with half of the items being strong (high-frequency) exemplars and half of the items weak (low-frequency) exemplars of the category, or a pure category, with all items being strong exemplars or all items weak exemplars. The items' category name and their unique initial letters were provided as retrieval cues at test. Performance of strong and weak items was compared between mixed categories and pure categories when the items were tested first within their categories, thus controlling for possible effects of output order. For both strong and weak items, no effect of category composition arose (Bäuml, 1997).

As a whole, these findings are largely consistent with the proposal that strengthening, as employed in the mixed-list paradigm, leads to blocking at test, which improves access to the relevant information at the expense of the access to the irrelevant material. Accordingly, the list-strength effect is typically present in free-recall tasks and is absent in recognition tasks. If output order is controlled, the effect is also absent in cued-recall tasks, which is consistent with the view that the inhibitory mechanism does not affect the items' retrieval routes or their memory representation.

#### *2.13.2.1.2 Relearning and interference paradigms*

Findings consistent with those from the mixed-list paradigm have been reported in two further strengthening paradigms, relearning and interference. In the relearning paradigm, strengthening effects are examined by presenting the relevant and irrelevant material together within one list and subsequently presenting the relevant material again for an additional study trial. This relearning condition is then compared with a condition in which there is no such reexposure of the relevant material.

Again, the idea of blocking suggests that, at least in free-recall tasks, retrieval competition may become biased because of the strengthening of a subset of the material and thus may increase recall of the relearned material at the expense of the material presented only once. Such effects, however, should not arise in recognition tests or tests using item-specific probes. A number of studies examined this latter prediction in cued-recall tests, in which the items' unique initial letters were provided as additional retrieval cues and output order was controlled by testing the target items first. In all these studies, relearning improved recall of the strengthened material but did not affect recall of the nonstrengthened material (Ciranni and Shimamura, 1999; Anderson et al., 2000a; Bäuml and Aslan, 2004). This finding is consistent with the assumption that strength-induced forgetting is mediated by blocking rather than by deactivation of retrieval routes or by deactivation of the item representation.

Both in retroactive and proactive interference, older studies had shown that strengthening of prior or subsequently encoded material can increase interference and thus increase forgetting of target material (for a review, see Crowder, 1976). Varying the degree of interpolated learning in a list-learning paradigm, Bäuml (1996) replicated this result and found that a higher degree of interpolated learning induced greater retroactive interference. In this experiment, output order was not controlled, and participants were free to recall the strengthened interpolated material prior to the (weaker) target material. In a second experiment, which was largely identical to the first experiment, output order was controlled, and participants were asked to recall the (weaker) target material first. No effect of degree of interpolated learning was observed (for a related result regarding proactive interference, see DaPolito, 1966; for further investigation, see Delprado, 2005). Again, these findings point to the action of a blocking mechanism, which is activated in memory tests that permit recall of items in any order.

#### *2.13.2.1.3 Summary*

Results from paradigms investigating strength-induced forgetting indicate that the strengthening of relevant material at encoding can trigger inhibitory processes to improve memory for the strengthened material at the expense of that for the not strengthened or irrelevant material. Strength-induced forgetting is present in free-recall tests and absent in recognition tests or cued-recall tests, in which output order is controlled. These results are consistent with the proposal that the enhanced accessibility of strengthened material and the reduced accessibility of nonstrengthened material result from blocking at test, in which early recall of stronger items prevents subsequent recall of the weaker ones. The results do not support the idea that the memory effects in these paradigms are caused by direct inhibitory effects on the irrelevant material's representation or its retrieval routes.

### 2.13.2.2 Retrieval-Induced Forgetting

The strengthening of relevant material at encoding can trigger inhibitory processes on the nonstrengthened irrelevant material. Strengthening of relevant material, however, does not only occur at encoding but may happen through retrieval as well. In fact, while relearning is an often employed method to emphasize memory for relevant material, retrieval of previously studied material can serve the same goal. One may even expect to find strengthening through retrieval to induce the same inhibitory processes as strengthening at encoding.

Experimental studies have shown that retrieval typically enhances later recall of the practiced material (Hogan and Kintsch, 1971) and can even be more powerful in its effect than relearning is (Carrier and Pashler, 1992; Roediger and Karpicke, 2006). The question arises of whether strengthening through retrieval also induces inhibitory processes and, if it does, whether such inhibition is mediated by the same competition bias as the inhibition underlying strengthening through relearning. On the basis of many computational models of memory, this might be expected, given that retrieval has often been assumed to reflect some form of relearning (e.g., Rundus, 1973; Raaijmakers and Shiffrin, 1981).

#### *2.13.2.2.1 Retrieval-practice paradigm*

In the retrieval-practice paradigm, a subset of learned material is repeatedly retrieved, and the effect of this manipulation on later memory for the practiced and unpracticed material is examined (Anderson et al., 1994; **Figure 3**). Memory is typically assessed by means of free recall, cued recall, and recognition tests. In addition, so-called independent probe tests are conducted, in which memory is assessed using cues at test that were not employed in earlier parts of the experiment. On the basis of retrieval competition and blocking, it might be assumed that retrieval simply strengthens the practiced material and thus causes blocking for the unpracticed material. Such blocking would increase recall for the practiced material and decrease recall for the unpracticed material, relative to control items in a no-practice condition. If true, then the effect of retrieval would mimic the effect of relearning.

A large number of free- and cued-recall experiments have addressed this issue in recent years. In these experiments, participants often learned categorized item lists and then practiced half of the items from half of the categories. At test, the category names were then provided as retrieval cues and the task was to recall the previously studied items that belonged to the category name. Relative to the control items from the unpracticed categories, retrieval practice typically improved recall of the practiced items and impaired that of the unpracticed items from the practiced categories (Anderson et al., 1994; Anderson and Spellman, 1995; Macrae and MacLeod, 1999; MacLeod and Macrae, 2001; Bäuml and Hartinger, 2002). This pattern of results first of all mirrors the beneficial and detrimental effects of strengthening at encoding, suggesting that the effect may be a result of blocking.

If the effects of retrieval were equivalent to those of relearning and only reflected biased competition and blocking, the detrimental effects of retrieval practice should be eliminated once item-specific probes were employed at test and output order was controlled. The issue was examined in experiments in which the detrimental effects of relearning and retrieval were compared directly. Participants learned categorized lists. At test, the category names

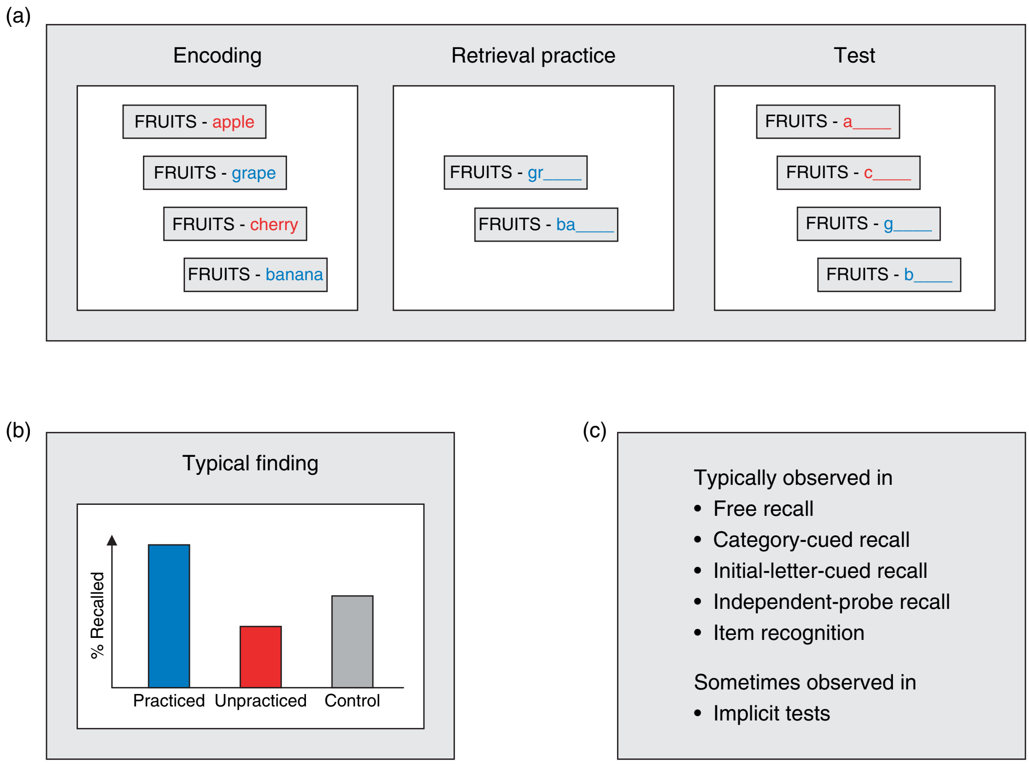


**Figure 3** Retrieval-induced forgetting. (a) The experimental paradigm. Participants study a categorized item list. In a subsequent retrieval-practice phase, half of the items from half of the studied categories are repeatedly retrieved. On the final test, participants are asked to recall all previously studied items. (b) The typical finding. Practiced items show higher recall rates, and unpracticed items show lower recall rates relative to the control items from the unpracticed categories. (c) Memory tests. Examples of memory tests in which retrieval-induced forgetting typically arises.

and the targets' initial letters were provided as retrieval cues. To control for output order, the targets were always tested first within their categories. Consistent with the results from the strengthening paradigms, no detrimental effect of relearning arose. In contrast, reliable forgetting arose in the retrieval practice condition (Anderson et al., 2000a), indicating that retrieval-induced forgetting reflects a recall-specific effect and is not caused by blocking (for related results, see Ciranni and Shimamura, 1999; Bäuml, 2002).

Further studies support the proposal that retrieval-induced forgetting does not reflect blocking by showing that the effect is not only present in free and category-cued recall but occurs in other types of tests as well. Using the so-called independent probe procedure, for instance, retrieval-induced forgetting has been reported to be cue independent, that is, to generalize to cues other than those used at study or retrieval practice (Anderson and Spellman, 1995; Anderson et al., 2000b; Saunders and MacLeod, 2006; Aslan et al., 2007b). Accordingly, retrieval practice of 'fruit-apple' was found to induce forgetting of 'banana' not only when banana was tested with the same cue as was used at study and retrieval practice ('fruit') but also when it was probed with a new, independent cue (e.g., 'monkey'). This property of cue independence is taken as strong support for the view that retrieval-induced forgetting is caused by inhibition (Anderson, 2003; for failures to find cue independence, see Williams and Zacks, 2001; Perfect et al., 2004).

Retrieval-induced forgetting has also been found in recognition tests (Hicks and Starns, 2004; Verde, 2004; Gómez-Ariza et al., 2005; Spitzer and Bäuml, in press). As outlined in section 2.13.1.2, recognition can be based on recollective processes and/or familiarity processes (Tulving, 1985; Jacoby, 1991). In retrieval-induced forgetting, the recognition tests provided evidence that retrieval practice affects both recollective and familiarity processes of the unpracticed material. Studies in which associative recognition was employed reported a reduction in recollective processes (Verde, 2004); studies in which item recognition was employed reported additional reductions in familiarity processes (Spitzer and Bäuml, in press). Regarding implicit memory tests, a mixed picture arises. Whereas some studies found reliable impairment in implicit tests (Veling and van Knippenberg, 2004), others failed to find an effect (Racsmany and Conway, 2006). Still others found effects in some tests but no effects in others (Perfect et al., 2002; see also Camp et al., 2005).

The results from all these studies are largely consistent with the assumption of an inhibitory mechanism that directly affects the representation of the unpracticed items itself. Because of such an impairment in item representation, all retrieval routes to the inhibited item should be less effective than without retrieval practice, and forgetting should be observed across a wide range of memory tests. The results from the studies employing recognition tests and tests using independent probes as cues support this view and are inconsistent with the hypothesis that the inhibition is the result of blocking or an effect on the retrieval routes between the inhibited item and its studied cue. Blocking assumes an inhibitory mechanism that operates at test. Here the proposal is that the inhibitory mechanism operates before the test in the retrieval practice phase of the experiment. In this phase, the not-to-be-practiced material is supposed to interfere and to be inhibited to reduce the interference and make retrieval of the target information easier (Anderson and Spellman, 1995; see also Anderson, 2003).

Two further lines of research support this view of retrieval-induced forgetting. First, response latency analysis sheds light on the dynamics of recall, allowing conclusions on the size of the underlying search set and the memory strength of the set's items (for a review, see Wixted and Rohrer, 1994). Applying such response latency analysis, Bäuml et al. (2005) found that retrieval practice reduces unpracticed items' recall probability but does not affect their response latency. This result mirrors typical effects of item strength manipulations as they occur as a result of variations in study time or study trials (Rohrer, 1996; Wixted et al., 1997), indicating that retrieval practice affects the memory strength of unpracticed items but does not prevent the items from being sampled. Second, a recent electrophysiological study reported retrieval-specific brain activities during the retrieval-practice phase, which were reflected in sustained prefrontal event-related potentials and correlated with the amount of forgetting in the later memory test (Johansson et al., 2007). The reported retrieval-specific effect indicates that retrieval-induced forgetting is the result of processes operating during retrieval practice and is not the result of blocking at test.

The inhibitory view of retrieval-induced forgetting presupposes some degree of retrieval competition and relational processing between single items. Consistently, Smith and Hunt (2000) reported reliable retrieval-induced forgetting if individuals encoded items in a relational way but not when they encoded them in an item-specific way, that is, by their features and distinctive qualities (regarding relational and item-specific processing, see Hunt and McDaniel, 1993). It is often assumed that positive moods encourage relational processing and negative moods encourage item-specific processing (e.g., Storbeck and Clore, 2005), thus raising the expectation that mood affects retrieval-induced forgetting. Bäuml and Kuhbandner (2007) examined the effect of positive and negative mood induction immediately before retrieval practice on retrieval-induced forgetting. Indeed, negative mood induction, but not positive mood induction, eliminated the forgetting.

Once material is processed in a relational way so that retrieval competition arises, the forgetting may be affected by the degree of interitem associations between the practiced and unpracticed material. Indeed, both instructions to interrelate to-be-practiced and not-to-be-practiced items in a meaningful way (Anderson et al., 2000b) and the use of strong pre-experimental associations between the two types of items (Bäuml and Hartinger, 2002; Bäuml and Kuhbandner, 2003) have been shown to eliminate retrieval-induced forgetting. Under conditions that simulate educational situations, Chan et al. (2006) even demonstrated that retrieval practice can benefit memory for the unpracticed material. These findings are consistent with a variant of item suppression in which items are represented as sets of features, and features that the unpracticed item shares with the practiced items are strengthened rather than inhibited. Because of this strengthening of some of the item's features, forgetting is reduced or eliminated and may even be reversed to show recall facilitation (for details, see Anderson, 2003).

At the core of the retrieval-practice paradigm is the action of an inhibitory mechanism that directly affects the representation of the irrelevant material. This effect is observable across a wide range of memory tests because the items' representation itself is affected. Note, however, that because item suppression induces a difference in relative strength between practiced and unpracticed items, the inhibitory process should also create a competition bias at test, favoring early recall of practiced items at the expense of unpracticed items. Moreover, because there is not only suppression of unpracticed material but also strengthening of the practiced material, this bias should be particularly strong, triggering additional blocking in free-recall tasks. Results from several studies are consistent with this prediction (e.g., Anderson et al., 1994).

#### *2.13.2.2.2 Output interference*

If retrieval of material can cause forgetting of nonretrieved material, then retrieval-induced forgetting should also occur in the course of a recall test. In principle, recall of a first item should cause inhibition of the still-to-be-remembered items, as should recall of the second item, the third item, and so on. As a result, recall performance at test should decline as a function of testing position. This pattern is exactly what has been known as output interference for more than 30 years. Output interference has been demonstrated in a number of studies (Smith, 1971; Roediger, 1974; Roediger and Schmidt, 1980) and, among other factors, was taken as evidence that recall is a self-limiting process (Roediger, 1978).

Originally, output interference was explained in terms of retrieval competition, assuming that recall of a first item strengthens the item and thus, because of biased retrieval competition, makes retrieval of the remaining items harder. This blocking account obviously disagrees with the explanation of retrieval-induced forgetting as it occurs in the retrieval-practice paradigm (see section 2.13.2.2.1). Arguably, however, retrieval-induced forgetting as studied in the retrieval-practice paradigm and retrieval-induced forgetting as studied in the output-interference paradigm should be mediated by similar mechanisms and might even be equivalent.

A blocking account of output interference predicts that the forgetting should disappear once item-specific probes are presented at test. Thus, recall should not decline with testing position if, for instance, the items' unique initial letters were provided as cues (see section 2.13.2.1.1). In contrast, if output interference was mediated by the same mechanism as the forgetting in the retrieval-practice paradigm, recall should decline with testing position regardless of whether item-specific cues were provided or not (see section 2.13.2.2.1). As it turned out, output interference effects are maintained in the presence of item-specific probes (Anderson et al., 1994; Anderson and Spellman, 1995; Bäuml, 1997), which supports the suggested equivalence of effects in the two paradigms.

The relation between the two paradigms was further examined in two studies in which the role of item strength and item similarity in output interference were examined (Bäuml, 1998; Bäuml and Hartinger, 2002). The two studies found effects of item strength and item similarity in output interference that mirrored those known from the retrieval-practice paradigm, which is consistent with the view that the same inhibitory mechanisms operate in the two paradigms. Given the evidence for item suppression in studies using the retrieval-practice paradigm (see section 2.13.2.2.1), these results suggest a role of item suppression in output interference as well.

#### *2.13.2.2.3 Summary*

Like relearning of relevant material, retrieval of relevant material can impair memory for irrelevant material. Results from the retrieval-practice paradigm suggest that retrieval triggers two processes: one process strengthening the practiced material and a second process inducing inhibition of the unpracticed material. These two processes create some difference in relative strength between practiced and unpracticed items and thus leave room for blocking. Going beyond blocking, however, retrieval affects the unpracticed material's representation itself. Such item suppression is at the core of retrieval-induced forgetting and implies that the inaccessibility of the irrelevant material is not restricted to free-recall tasks but generalizes to a wide range of memory tests. The results also indicate that the detrimental effects of retrieval and relearning are mediated by different mechanisms.

### 2.13.2.3 Directed Forgetting

Relearning and retrieval practice may be regarded as forms of memory updating, in which part of previously studied material is reexposed or retrieved, suggesting that it is more relevant than the remaining material (Anderson and Schooler, 1991). Inhibitory processes then act on the seemingly less relevant material, either by blocking its access during recall or by directly affecting the material's representation itself. A different form of updating may arise in situations in which new information, such as the new computer password, has to displace old information, for example, the expired password. In this case, memory for the new relevant information would benefit if memory for the irrelevant out-of-date information was reduced. Whether such updating is part of our memory and is mediated by inhibitory processes has been studied in list-method directed forgetting.

#### 2.13.2.3.1 List-method directed forgetting

In list-method directed forgetting, participants learn two lists of items. After learning List 1, they receive a cue to either forget or continue remembering this list before studying List 2. After learning List 2, a recall or recognition test is conducted in which participants are asked to remember the previously studied items, including those the participants were originally cued to forget. Memory for List 1 and List 2 items is then compared between the two conditions (Bjork, 1970, 1989; **Figure 4**).

The results from numerous recall experiments show two effects of the forget cue: reduced recall of List 1 items, referred to as forgetting and improved recall of List 2 items, referred to as enhancement (for a review, see MacLeod, 1998). These effects provide the first evidence for memory updating in this paradigm, demonstrating reduced accessibility for the out-of-date information and enhanced accessibility for the new information. Arguably, the forgetting of List 1 items might be a result of demand characteristics, because participants may not try as hard to recover the to-be-forgotten List 1 items as they do for the to-be-remembered List 2 items. The effect of the forget cue, however, does not disappear if money is offered for recalled List 1 items (MacLeod, 1999), indicating that the effect probably is not a result of demand characteristics (for a recent variant of list-method directed forgetting, see Szpunar et al., in press).

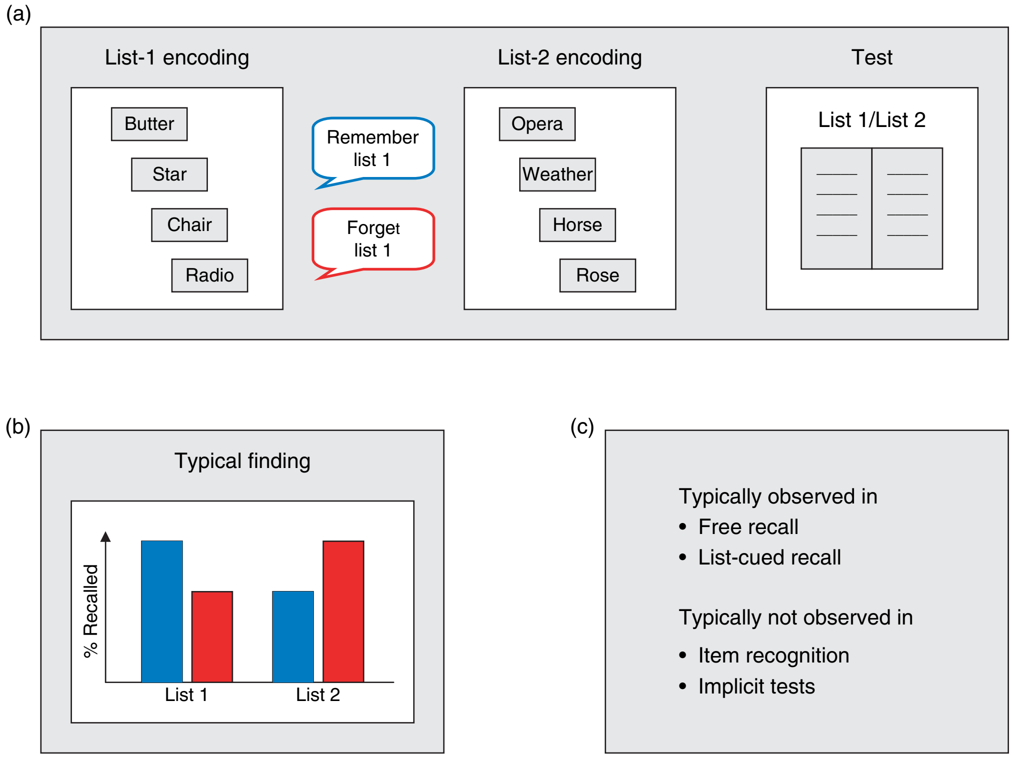


**Figure 4** List-method directed forgetting. (a) The experimental paradigm. Participants study two lists of items and, after the presentation of List 1, receive a cue to either forget or continue remembering this list before studying List 2. After study of List 2, a recall test is conducted in which participants are asked to recall all of the previously presented items, including those the participants were originally cued to forget. (b) The typical finding. Compared with remember-cued participants, forget-cued participants typically show impaired recall of List 1 items and improved recall of List 2 items, referred to as the forgetting and the enhancement induced by the forget cue. (c) Memory tests. Examples of memory tests in which list-method directed forgetting typically arises and in which it typically does not arise.

In free-recall tests, participants in the forget condition show a tendency to recall List 2 items before List 1 items (Geiselman et al., 1983). As a result, the effect of the forget cue on List 1 items could be a result of blocking and output interference, in which early recall of List 2 items impairs subsequent recall of List 1 items. The two effects of the forget cue, however, have been found regardless of whether the two lists were recalled simultaneously in any order the participants wished (i.e., with a tendency to recall List 2 items before List 1 items) or whether they were recalled successively with List 1 items recalled prior to List 2 items (Geiselman et al., 1983; Zellner and Bäuml, 2006). This result indicates that list-method directed forgetting does not reflect effects of blocking and output interference.

List-method directed forgetting has also been assessed by means of recognition tests. In most of these studies, no effect of the forget cue emerged for either List 1 items or List 2 items (Geiselman et al., 1983; Basden et al., 1993; Sego et al., 2006; for an exception, see Benjamin, 2006). Impairments on List 1 recognition, however, were found when participants were required to make source memory judgments (Geiselman et al., 1983). On the basis of the recollection/familiarity distinction, this finding suggests that the forgetting in this paradigm reflects primarily a deficit in recollection and not in familiarity. No effects of the forget cue arose in implicit memory tasks (Basden et al. 1993; Basden and Basden, 1996).

Two particularly prominent accounts of list-method directed forgetting are selective rehearsal and inhibition. The selective rehearsal account assumes that during List 2 encoding participants in the remember condition rehearse both List 2 and List 1 items, whereas in the forget condition, the forget cue leads to selective rehearsal activities on List 2 items, thus improving later recall of List 2 at the expense of List 1 (Bjork, 1972). The inhibition account assumes that, by inhibiting List 1 items, the forget cue deactivates retrieval routes to List 1 items and, because of the resulting decrease in the items' interference potential, simultaneously improves access to List 2 items (Geiselman et al., 1983). Because the selective rehearsal hypothesis attributes directed forgetting to differences in encoding, it predicts effects on recall and recognition tests. The inhibition account attributes directed forgetting to effects on the List 1 items' retrieval routes, and thus the forgetting should be present in recall but should be absent in recognition. The above-mentioned failure to find directed forgetting on recognition tests supports the inhibition account.

Further evidence for the inhibition view arises from an experiment by Geiselman et al. (1983). They used a variant of the standard paradigm, in which participants alternately learned items intentionally and incidentally. Indeed, all participants were told to learn one item and judge the pleasantness of the next one. For both learn and judge items, the standard pattern of directed forgetting arose with reduced recall of List 1 items and improved recall of List 2 items. This result challenges the selective rehearsal hypothesis, because participants in the remember condition should not have tried to rehearse the incidental List 1 items and, rather, should have focused their rehearsal on the learn items. Incidental List 1 items thus should have shown the same performance in the remember as in the forget condition, which was not the case.

For most of the paradigms discussed in this chapter, there is broad consensus that inhibition operates on an item level. In contrast, in list-method directed forgetting it has been suggested that the inhibition operates on a list-level basis. According to this view, List 1 items form a unit, and the presence of the forget cue induces inhibition of the whole unit. Evidence in favor of this view comes from the Geiselman et al. (1983) observation that incidentally learned List 1 items share the same fate as intentionally learned List 1 items. Further support for the view arises from part-list reexposure studies. In these studies, after learning of the two lists, a subset of the List 1 items was reexposed as part of a recognition test before all previously studied items were to be recalled on a final recall test. The results provided evidence that part-list reexposure eliminates the forgetting of the remaining items (Bjork et al. 1973; Goernert and Larson, 1994; Bjork and Bjork, 1996), which is consistent with the view that the inhibition operates on a list-level basis. More recently, however, the findings were challenged by results suggesting that part-list reexposure reinstates mainly reexposed items and not the entire List 1 episode (Basden et al., 2003).

A priori, one might like to assume that the presence of the forget cue in the list-method directed forgetting procedure is sufficient to create the forgetting of List 1 items. As the results from two lines of research show, however, this is not the case. First, it has been found that the presentation of the forget cue creates forgetting only if it is presented before List 2 encoding, but not if it is presented after the encoding (Bjork, 1970). Second, the effect of the forget cue arises only if there is additional List 2 encoding. That is, the forgetting of List 1 items disappeared if the forget cue was provided, but no additional List 2 learning took place (Gelfand and Bjork, 1985; Pastötler and Bäuml, in press). This finding indicates that the presence of the forget cue per se is not sufficient to create list-method directed forgetting. In particular, the result suggests that the inhibitory mechanism in this paradigm operates during List 2 encoding.

Accounts of directed forgetting are typically one-mechanism accounts according to which the same mechanism underlies the two effects of forgetting and enhancement. Although enhancement and forgetting in directed forgetting often go hand in hand, recently some exceptions to this rule have been observed, and forgetting has been found without enhancement (Conway et al., 2000; Sahakyan and Delaney, 2003, 2005; Zellner and Bäuml, 2006), and enhancement obtained without forgetting (Macrae et al., 1997; Benjamin, 2006). These dissociations suggest the action of two separate mechanisms, one mediating the forgetting and the other mediating the enhancement. Consequently, a two-mechanism account was suggested, according to which the forgetting is caused by some form of inhibition, whereas the enhancement results from a change in people's List 2 encoding with more elaborate encoding in the forget than in the remember condition (Sahakyan and Delaney, 2003).

At the core of list-method directed forgetting is the action of an inhibitory mechanism that induces effects on the irrelevant material by affecting the items' retrieval routes to their cue. Such inhibition should also trigger blocking. The difference in retrieval strength between inhibited List 1 items and noninhibited List 2 items should create biased retrieval competition, with relevant items being recalled prior to irrelevant items. Although there is evidence for the predicted recall order (Geiselman et al., 1983), to date such blocking effects have not been uncovered (Geiselman et al., 1983; Zellner and Bäuml, 2006).

#### *2.13.2.3.2 Item-method directed forgetting*

In list-method directed forgetting, relevant new material is encoded after irrelevant old information, initiating updating processes on the out-of-date information. However, relevant and irrelevant material may also be presented interspersed. In this case, different processing of the two types of information might be achieved by triggering inhibitory processes on each single irrelevant item. Whether such processes can affect later accessibility of the irrelevant information has been studied in item-method directed forgetting.

In item-method directed forgetting, participants study a list of items in which a cue to remember or forget the item follows presentation of each single item. Later, a memory test is conducted in which both to-be-remembered (TBR) and to-be-forgotten (TBF) items have to be recalled or recognized (Woodward and Bjork, 1971; see **Figure 2(a)** for a formally related paradigm). Performance for the relevant and irrelevant material is directly compared without reference to any additional baseline conditions (for a review, see MacLeod, 1998). Results from free-recall experiments typically reveal a difference in performance between TBR and TBF items, with better recall for TBR than TBF items, thus showing that the cuing is effective (Davis and Okada, 1971; Woodward and Bjork, 1971; Basden et al., 1993). Moreover, as is true in list-method directed forgetting, the effect is probably not a result of demand characteristics, because it does not disappear if money is offered for recall of the TBF items (MacLeod, 1999).

List-method directed forgetting is present in recall but is absent on recognition tests. In contrast, the difference between TBR and TBF items in item-method directed forgetting has been observed in both recall and recognition tests (Davis and Okada, 1971; MacLeod, 1989; Basden et al., 1993). Regarding the contribution of recollection and familiarity on recognition performance, the effect of the forget cue seems to reflect a difference in recollective processes rather than in familiarity. This is indicated because the difference in performance has been found to be present in remember judgments but not in know judgments (Gardiner et al., 1994; Basden and Basden, 1996). A different performance for TBR and TBF items was also found in implicit memory tasks (MacLeod, 1989; Basden and Basden, 1996), although the effect does not seem to be present in all types of tasks (MacLeod and Daniels, 2000).

The simplest view of these findings is a strengthening view according to which TBF and TBR items only differ in the degree to which the single items are rehearsed and strengthened in response to the respective cue (Bjork, 1972; Basden et al., 1993; see also MacLeod, 1998). Such an interpretation is consistent with the finding of differences between TBR and TBF items in most types of memory tests, including recognition and some implicit memory tasks. Following this view, the forget cue would not inhibit retrieval routes or the memory representation of the TBF items. Because of the induced difference in relative strength between the two types of items, the forget cue, however, might create some blocking at test, with early recall of (stronger) TBR items blocking access to the (weaker) TBF items. If true, item-method directed forgetting would be similar in character to what occurs in the list-strength effect (see section 2.13.2.1.1). Moreover, item-method directed forgetting would reflect an instructional variant of the list-strength effect.

Our knowledge of the role of inhibitory processes in the list-strength effect is largely based on comparisons between performance in the mixed-list condition and performance in two pure-list conditions that are used as baseline conditions (see section 2.13.2.1.1). Item-method directed forgetting may also create a form of mixed list, consisting partly of the stronger TBR items and partly of the weaker TBF items. In this case, however, performance is typically not compared with pure-list baseline conditions. Such comparisons would strongly improve the database to derive a more clearcut indication of the role of inhibitory processes in item-method directed forgetting. Until then, it seems that inhibition may play a role in item-method directed forgetting experiments, but that this effect is restricted to blocking and is not caused by direct effects on the items' retrieval routes or the items' memory representation.

#### *2.13.2.3.3 Summary*

The presence of a forget cue can induce forgetting of irrelevant material. Depending on whether the relevant material is presented subsequent to the irrelevant material (the list method) or relevant and irrelevant material are presented interspersed (the item method), different effects arise. In list-method directed forgetting, the effect of the forget cue is found in free-, and list-cued recall tests but not in recognition or implicit memory tasks. The effect is likely to be the result of some deactivation of the retrieval route between the TBF items and their cue. The representation of the TBF items itself, however, does not seem to be affected. In item-method directed forgetting, the effect of the forget cue can be found across a wide range of memory tests, including free recall and recognition tasks. The results are largely consistent with a strengthening view, according to which the two cues lead to items of different memory strength because of selective rehearsal. While this difference in relative strength may create blocking in recall tests, no clearcut evidence for other forms of inhibitory processes, such as direct effects on retrieval routes or item representations, has yet been identified. It thus seems that quite different mechanisms are at work in list-method and item-method directed forgetting.

### 2.13.2.4 Think/No-Think Impairment

In item-method directed forgetting, a forget cue is provided after presentation of an item to inform participants that the item is irrelevant and will not be tested later. As summarized in the previous section, the results from a number of studies have shown that, in response to such a cue, rehearsal of an item can be stopped, thus demonstrating that forget cues at encoding can be effective. The question arises of whether a forget cue can not only stop rehearsal but may stop retrieval as well (Weiner and Reed, 1969). Evidence for this type of proposal arises from studies using the think/no-think paradigm.

The think/no-think paradigm is a memory adaptation of the go/no-go task, which is typically used to study control of prepotent motor responses. In the think/no-think paradigm, participants study weakly related word pairs (e.g., butter-opera) and are trained to answer with the appropriate associate (target) upon presentation of its counterpart (cue). After the training, participants engage in a think/no-think task. In each trial of the task, the cue word (butter) is provided and participants are required either to remember (think) or to actively suppress any thought (no-think) about its corresponding target (opera) and not let it enter consciousness. A large number of such trials is typically conducted. In a final cued-recall test, participants are then asked to recall the targets in response to the original stimulus cue, regardless of whether in the intermediate phase they were instructed to think about the item or to suppress it. As a variant of this testing procedure, a semantically related word (music) may be presented as cue rather than the original stimulus cue, thus permitting a test of cue-independent forgetting in this paradigm (Anderson and Green, 2001; **Figure 5**).

Results from several studies showed improved recall of think items and impaired recall of no-think items relative to baseline items, which were neither remembered nor suppressed in the intermediate think/no-think phase (Anderson and Green, 2001;

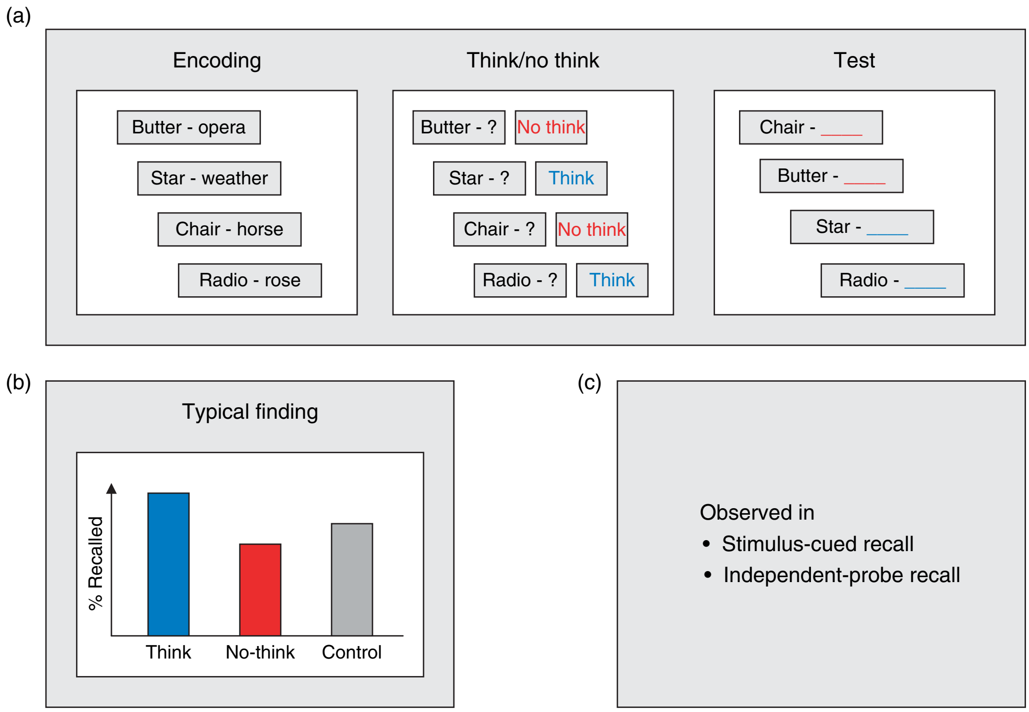


**Figure 5** Think/no-think impairment. (a) The experimental paradigm. Participants study weakly related cue–target pairs and are trained to answer with the target upon presentation of its cue. After the training, participants engage in the think/no-think task. In each trial of the task, they are provided with a cue word and are required to either remember (think) or actively suppress any thought (no-think) about its corresponding target. On a later test, all targets are tested given their associate as the retrieval cue. (b) The typical finding. Think items are recalled better and no-think items are recalled worse than control items, which were neither remembered nor suppressed in the intermediate think/no-think task. (c) Memory tests: Examples of memory tests in which think/no-think impairment has been observed.

Anderson et al., 2004; Hertel and Calcaterra, 2005; Depue et al., 2006). In particular, the effect did not only arise if at test the original stimulus cue was presented, but was also present if a semantically related independent probe was provided (Anderson and Green, 2001; Anderson et al., 2004). Again, the effect does not seem to be a result of demand characteristics, as the forgetting has been found to be still present if money was offered as a reward for each recalled no-think item (Anderson and Green, 2001).

The few studies that to date reported successful forgetting in the think/no-think paradigm indicate that the forgetting in this paradigm arises if the number of no-think trials is high (16 trials) but is not present if the number of such trials is relatively low (one or four trials). Moreover, even with a high number of no-think trials, the effects are typically small, although the forgetting can increase somewhat if emotional material rather than neutral material is employed in the experiment (Depue et al., 2006). Researchers also failed to replicate the finding, despite several careful attempts to do so (Bulevich et al., in press), which suggests that the forgetting in this paradigm may not be very reliable.

Anderson and Green (2001) argued that the forgetting in the think/no-think paradigm is caused by inhibition. According to this account, during no-think trials, the memory representation of the targets is reduced so that accessibility is lowered regardless of which cue is provided and which retrieval route is used. In consequence, the forgetting should be observed across a wide range of memory tests, including independent-probe tasks, recognition tasks, or implicit memory tasks. Although there is evidence for cue independence in this paradigm (Anderson and Green, 2001; Anderson et al., 2004; but see Bulevich et al., in press, for failures to get the effect), no studies have yet been reported examining think/no-think impairment in recognition or implicit memory tests. Using imaging techniques, Anderson et al. (2004) examined neural correlates of the forgetting during no-think trials. They identified an interaction between prefrontal cortex and hippocampus, which was related to the forgetting of no-think items on the final recall test and was interpreted as evidence for inhibition. However, because there was also increased activity in other brain regions during no-think trials, it was argued that the forgetting might also be a result of subjects' attempts to think about something else rather than to inhibition (Hayne et al., 2006).

Indeed, rather than reflecting item suppression, the forgetting in this paradigm might also be caused by some form of inaccessibility created through associative interference. This might occur if, for instance, participants adopt a strategy of thinking about other, distracting words during no-think trials, thereby building new associations to the cue and increasing (retroactive) interference (Hertel and Calcaterra, 2005; Bulevich et al., in press). Because interference effects are typically restricted to situations in which the original cue is provided at test, such noninhibitory accounts of the phenomenon would not predict forgetting when independent probes are provided. The reported failure to find forgetting when independent probes are provided as cues (Bulevich et al., in press) thus supports the associative interference account of the phenomenon. In contrast, Anderson and colleagues' reports of cue independence (Anderson and Green, 2001; Anderson et al., 2004) challenge the interference account and support the suppression account. Obviously, further research is warranted.

The results from the think/no-think paradigm suggest that cues to stop retrieval of an item can cause later forgetting of the item. Item-method directed forgetting shows that cues to stop rehearsal of an item can also be effective. While these lines of evidence converge on the view that cues to stop the processing of items, be it at encoding or retrieval, can be successful, there is evidence that the two forms of stopping are nonetheless different. First, stopping rehearsal seems to be relatively easy for participants, typically inducing strong performance differences between TBR and TBF items. In contrast, stopping retrieval seems to be hard, and participants may even fail to show forgetting in this task. Second, the stopping of rehearsal does not seem to be inhibitory in the sense that a TBF item is inhibited in its representation or its retrieval routes. In contrast, the stopping of retrieval has been argued to induce deactivation of the item representation, so that the item becomes unavailable. If true, stopping rehearsal and stopping retrieval may be quite different things in memory.

### 2.13.2.5 Part-List Cuing Impairment

What is common to the paradigms described earlier (in the subsections in 2.13.2 to this point) is that inhibitory mechanisms operate to emphasize accessibility of relevant material at the expense of that for irrelevant information. Inhibition thus seems to serve an adaptive goal and to support memory to function efficiently. On the other hand, there is evidence that inhibition is not always adaptive and goal directed. This is indicated by an example from the memory literature in which inhibitory processes emphasize accessibility of irrelevant material at the expense of that for relevant information. The example is part-list cuing impairment.

#### *2.13.2.5.1 Beneficial and detrimental effects of cuing*

There is broad agreement in the literature that the presence of adequate retrieval cues is crucial for successful episodic memory (e.g., Tulving, 1974). Consistently, cuing has been found to facilitate recall in many situations. For instance, if a categorized list with several items from each category is presented to participants and, at test, the category names or one item from each category are provided as retrieval cues, then such cuing typically enhances recall compared to unaided free recall (Tulving and Pearlstone, 1966; Tulving and Psotka, 1971).

Cuing, however, is not always facilitatory and can even be detrimental. If participants learn a categorized list and, at test, receive several items from each category as retrieval cues, then such part-list cuing often reduces recall performance for the remaining items, compared with the condition in which just one category exemplar is provided as a retrieval cue (Slamecka, 1968; Roediger, 1973; for reviews, see Nickerson, 1984, or Roediger and Neely, 1982). In general, if more part-list cues are provided than necessary to remind participants of the various categories, or subjective units, cuing can be detrimental (Basden and Basden, 1995).

Prior work assumed that part-list cuing impairment is caused by blocking (Roediger, 1973; Rundus, 1973). The idea was that reexposure of items as cues strengthens these items' representation. During attempts to recall the noncue items at test, this strengthening of the cue items then should lead participants to covertly retrieve cue items before noncue items and thus block recall of the noncues. Part-list cuing, therefore, should mimic the effects of relearning, in which reexposure has been shown to block recall of the target material (see section 2.13.2.1.2).

Prior work demonstrated that the detrimental effects of relearning disappear once item-specific probes, such as the targets' unique initial letters, are provided to aid recall of the items. Thus, if part-list cuing impairment, like the detrimental effects of relearning, was caused by blocking, then part-list cuing impairment should also be absent if item-specific probes were provided. The issue was directly addressed in an experiment by Bäuml and Aslan (2004). Participants learned category exemplars consisting of target and nontarget items. In a subsequent phase, the nontarget items were reexposed, either for relearning (i.e., for a second study trial) or for use as retrieval cues at test. This reexposure occurred immediately before test, mimicking the typical part-list cuing procedure, or separated from test by a distractor task, mimicking typical part-list relearning. At test, the category-plus-first-letter cues of the target items were presented, and participants were instructed to recall the target items.

As expected from the relearning literature, part-list relearning had no detrimental effect on the target material. In contrast, part-list cuing had a detrimental effect. This held true both when the reexposure occurred immediately before test and when reexposure was separated from test by a distractor task. This finding indicates that part-list cuing differs from relearning and that its detrimental effects are not caused by blocking. In particular, it shows that part-list cuing impairment reflects an instructional effect. Reexposure induces forgetting when participants are oriented to use the reexposed items as retrieval cues (part-list cuing) but does not induce forgetting when the reexposed items are presented for an additional study trial (part-list relearning).

Results from recognition studies support the view that part-list cuing differs from relearning and other strengthening effects. Indeed, while strength-induced forgetting is typically absent in recognition tests, reliable part-list cuing impairment was found when memory for the noncues was assessed by means of a recognition task (Todres and Watkins, 1981). Part-list cuing impairment also arose in speeded recognition (Neely et al., 1983; Oswald et al., 2006). Because recognition performance is assumed to rely more on familiarity than recollection when participants are required to make recognition decisions very quickly (e.g., Yonelinas, 2002), this finding suggests that part-list cuing does not only affect recollective processes but affects the familiarity of the noncue items as well.

There is evidence that part-list cuing impairment is also present in recall tasks that employ independent probes (see section 2.13.2.6.1). Aslan et al. (2007a) reported a repeated-testing experiment in which, in the first test, participants were provided with part-list cues and were asked to recall half of the target items when cued by the items' unique initial letters. After a delay, a second test was conducted in which no part-list cues were provided and participants were asked to recall the remaining targets by means of independent probes, that is, probes that were not used in a previous phase of the experiment. Part-list cuing impairment was present in both tests, indicating that independent probes do not eliminate the forgetting.

The results from all these studies are consistent with an inhibitory view of part-list cuing impairment according to which part-list cuing triggers inhibitory processes that directly affect the item representation of the noncues. In this sense, the effect may mimic the effect of retrieval practice in retrieval-induced forgetting (see section 2.13.2.2). Indeed, several studies compared the detrimental effects of retrieval practice and part-list cuing directly within a single experiment (Bäuml and Kuhbandner, 2003; Bäuml and Aslan, 2004; Zellner and Bäuml, 2005). In all these cases, the same qualitative and quantitative effects arose. These findings agree with the view that part-list cuing leads to instructed covert retrieval of cue items and causes inhibition of noncue items very similar to how overt retrieval in retrieval-induced forgetting inhibits nonretrieved items (Bäuml and Aslan, 2004).

Retrieval-induced forgetting has been shown to be lasting and to still be present when item-specific probes are provided (see section 2.13.2.6.1). Consistent with the inhibitory view of part-list cuing impairment, part-list cuing impairment can also persist, even with item-specific probes (Bäuml et al., 2002; Bäuml and Aslan, 2004, 2006). On the other hand, there are demonstrations that, under certain conditions, the cuing effect can disappear with a delay (Basden and Basden, 1995; Bäuml and Aslan, 2006) and can be absent in the presence of item-specific probes (Aslan and Bäuml, in press). Bäuml and Aslan (2006) identified associative relations at encoding as a crucial factor in part-list cuing impairment. Data suggest that the detrimental effect of part-list cues is mediated by inhibition in situations with a relatively low level of interitem associations and is mediated by noninhibitory mechanisms in situations with a relatively high level of interitem associations. Thus, apparently more than one mechanism is involved in this form of forgetting.

#### *2.13.2.5.2 Summary*

Providing a subset of studied material as retrieval cues for recall of the remainder often does not enhance but rather reduces accessibility of relevant targets. Such part-list cuing impairment reflects an instructional effect, with reexposure of items being detrimental only if participants are oriented to use the items as retrieval cues. Part-list cuing differs from part-list relearning and, in many situations, is the result of the action of an inhibitory mechanism that affects the noncue items' representation directly. Part-list cuing impairment thus mirrors retrieval-induced forgetting, in which retrieval practice affects the representation of the nonretrieved items. In contrast to retrieval-induced forgetting, however, part-list cuing is not adaptive or goal directed but, rather, provides an example in which inhibitory processes can impair access to relevant information rather than enhance it.

### 2.13.2.6 Developmental Trajectory of Inhibitory Processes

The role of inhibition in cognition is of central importance in the literature on cognitive development. This stems in part from findings reporting poor performance of young children and older adults in a number of inhibition tasks (Simpson and Foster, 1986; Tipper et al., 1989; Hartman and Hasher, 1991; Hasher et al., 1997). In particular, it is attributable to the hypothesis that young children and older adults suffer from a general deficit in inhibitory function (Hasher and Zacks, 1988; Bjorklund and Harnishfeger, 1990). Such a general deficit in inhibitory function might also apply to memory and be at the heart of the reduced memory performance of young children and older adults. It thus is important to examine the performance of young children and older adults in the inhibitory paradigms addressed earlier (in the subsections in 2.13.2 to this point).

The hypothesis of a general inhibitory deficit in young children and older adults indicates that the two age groups show problems across the whole range of inhibitory paradigms reviewed above. This holds while the results reported in the subsections in 2.13.2 to this point suggest the action of quite different inhibitory mechanisms in the different paradigms. Knowledge on the developmental trajectory in the single paradigms would improve our understanding of memory development and would also improve our understanding of the development of cognitive inhibition in general. In recent years, a number of results emerged regarding young children's and older adults' retrieval-induced forgetting, directed forgetting, and part-list cuing impairment. These results are reviewed in the next sections.

#### *2.13.2.6.1 Retrieval-induced forgetting*

In children, retrieval-induced forgetting has been studied using both cued recall and recognition tasks at test. Zellner and Bäuml (2005) reported two experiments using verbal categorized lists and category-cued recall tasks at test. First graders, second graders, fourth graders, and young adults were tested. All four groups of participants showed the standard pattern of retrieval-induced forgetting with improved recall of practiced items and impaired recall of unpracticed items. In particular, there were no differences in the amount of forgetting across participant groups, suggesting that the inhibition was effective in young children (**Figure 6(a)**).

Using pictorial material, Ford et al. (2004) examined retrieval-induced forgetting in 7-year-olds by means of a yes/no recognition task in the practice phase and a category-cued recall test and a recognition test in the final test phase. In both cases, robust retrieval-induced forgetting was found. Furthermore, the magnitude of the effect did not differ between children and young adults. Analogous results were reported by Lechuga et al. (2006), who examined retrieval-induced forgetting in 8- and 12-year-old children. Related results were obtained in studies using the selective postevent review (questioning) procedure with 5- and 9-year-olds (Conroy and Salmon, 2005) and 5- to 6-year-olds (Williams et al., 2002). Review of some events impaired memory for nonreviewed events with comparable impairment in all age groups.

Only very few studies exist to date in which retrieval-induced forgetting was studied in older adults. In a nondevelopmental study, Moulin et al. (2002) found retrieval-induced forgetting in Alzheimer disease patients and healthy age-matched older adults in both a standard category-cued recall and a category generation task. While this study demonstrated reliable forgetting in older adults, it left open the question of whether the effect differs quantitatively from that in younger adults. Aslan et al. (2007b) examined retrieval-induced forgetting in younger and older adults and found equivalent amounts of

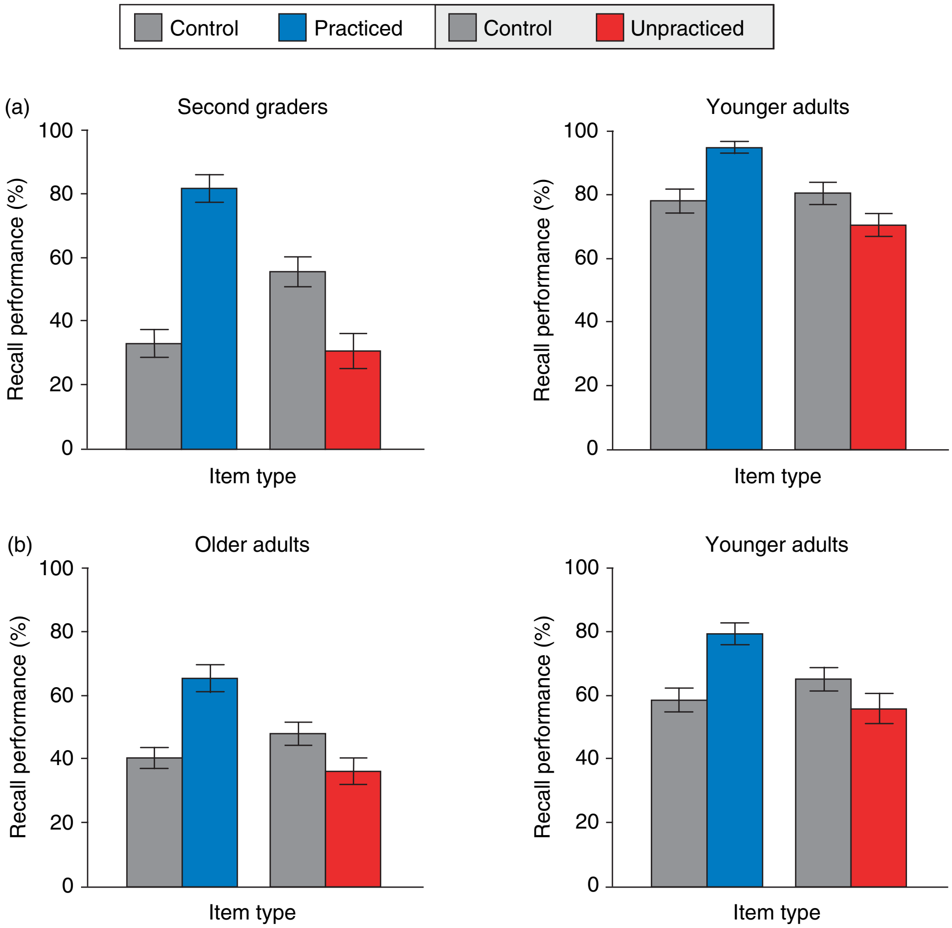


**Figure 6** Retrieval-induced forgetting in young children and older adults. (a) Recall percentage (and standard error) of retrieval-practiced and not-retrieval-practiced items and of their (separate) control items in second graders and younger adults. For both participant groups, the data show beneficial effects of retrieval practice on practiced items and detrimental effects of retrieval practice on unpracticed items. From Zellner M and Bäuml K-H (2005) Intact retrieval inhibition in children's episodic recall. *Mem. Cogn.* 33: 396–404. Psychonomic Society, Inc., Experiment 1. Adapted with permission. (b) Recall percentage (and standard error) of retrieval-practiced and not-retrieval-practiced items and of their (separate) control items in younger and older adults. For both participant groups, the data show beneficial effects of retrieval practice on practiced items and detrimental effects of retrieval practice on unpracticed items. From Aslan A, Bäuml K-H, and Pastötter B (2007) No inhibitory deficit in older adults' episodic memory. *Psychol. Sci.* 18: 111–115. Blackwell Publishing, Experiment 1. Adapted with permission.

forgetting in the two age groups. This result held both when category names and when independent probes were provided as retrieval cues, suggesting that, in both age groups, the inhibition affects the items' memory representation itself (**Figure 6(b)**). Related results were again obtained when using the selective postevent review procedure (Koutstaal et al., 1999).

Thus, retrieval-induced forgetting seems to be present over most of the lifespan and to differ hardly, if at all, between young children, younger adults, and older adults. In particular, the results suggest that, in all these age groups, the effect is caused by the same inhibitory mechanism, which affects the nonretrieved items' representation itself. Thus, no evidence for an inhibitory deficit in young children or older adults arises in this type of task.

### *2.13.2.6.2 Directed forgetting*

1. List-method directed forgetting

A number of studies examined list-method directed forgetting in young children (e.g., Bray et al., 1983; Harnishfeger and Pope, 1996). The results from these studies suggest that young children show problems in this type of task. In the study by Harnishfeger and Pope (1996), for instance, first, third, and fifth graders and young adults were compared. First and third graders failed to show directed forgetting and showed hardly any effect of the forget cue at all. Normal directed-forgetting performance, however, was present from fifth grade on. The inhibition mechanism apparently develops over the elementary school years (Figure 7(a)).

There are three published studies to date that have examined list-method directed forgetting in older adults. In the first study, Zacks et al. (1996) used a variant of the task in which several short lists had to be studied and recall performance was measured cumulatively after presentation of all lists. A greater amount of forgetting was found for younger than for older adults. The results, however, were affected by floor effects. In a second study, Sego et al. (2006) followed previous work by Geiselman et al. (1983) and let younger and older adults alternately learn items intentionally and incidentally. For both types of items, largely identical forgetting was found in the two age groups. Zellner and Bäuml (2006) compared younger and older adults' directed forgetting in three experiments, in which the forget cue was varied within and between participants, the two lists were unrelated or related to each other, and recall of the lists was required simultaneously or successively. No age-related difference in directed forgetting performance emerged in any of the three experiments (Figure 7(b)).

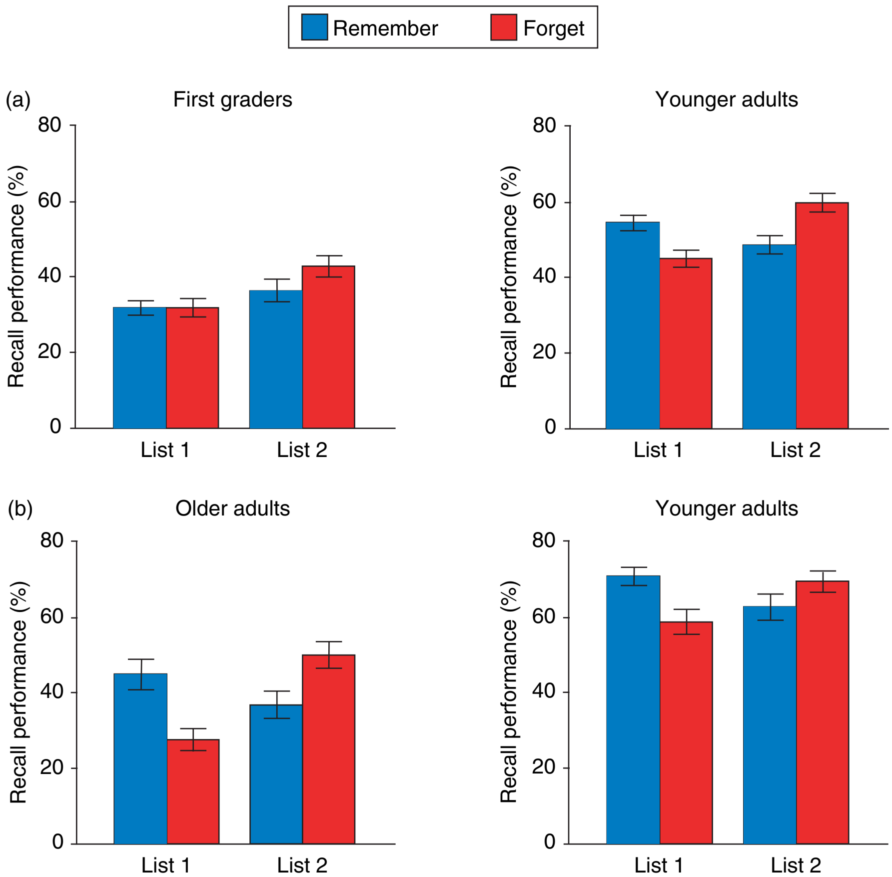


**Figure 7** List-method directed forgetting in young children and older adults. (a) Recall percentage (and standard error) of List 1 and List 2 items as a function of whether a remember or forget cue was provided between learning of the two lists. While younger adults show the standard pattern of directed forgetting, for young children no reliable effect of the forget cue arises. This holds for both List 1 and List 2 items (K.-H. Bäuml, M. Zellner, and A. Aslan, unpublished data). (b) Recall percentage (and standard error) of List 1 and List 2 items as a function of whether a remember or forget cue was provided between learning of the two lists. Both younger adults and older adults show the standard pattern of List-method directed forgetting. From Zellner M and Bäuml K-H (2006) Inhibitory deficits in older adults – List-method directed forgetting revisited, *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 290–300, American Psychological Association, Experiment 3. Adapted with permission.

Thus, while young children fail to show list-method directed forgetting, older adults seem to show intact forgetting. This result suggests that the underlying inhibitory mechanism develops in later childhood. Once developed, however, it remains intact with increasing age. The inhibitory mechanism underlying list-method directed forgetting thus differs in its developmental trajectory from that underlying retrieval-induced forgetting.

2. Item-method directed forgetting

Few studies have examined item-method directed forgetting in young children. Posnansky (1976) found better recall of TBR items than TBF items in both third and seventh graders, with no difference in the effect of the forget cue between the two age groups. Foster and Gavelek (1983) reported that even first graders recalled more TBR than TBF items, although the effect of the forget cue was smaller for first than for fifth graders. Regarding older adults' directed forgetting, several studies found a reliable difference between TBR and TBF items with increasing age. The difference, however, was smaller in older adults than in younger adults (Zacks et al., 1996; Earles and Kersten, 2002; Dulaney et al., 2004), which indicates that older adults show deficient directed forgetting in this type of task.

Together the results suggest that both young children and older adults show deficits in item-method directed forgetting. Following the strengthening view of item-method directed forgetting, these findings, however, do not imply inhibitory deficits in young children and older adults but, rather, may indicate differences in the degree to which the two age groups are able to strengthen relevant material.

#### 2.13.2.6.3 Part-list cuing impairment

There seems to be only one study in the literature that examined part-list cuing impairment in young children. Zellner and Bäuml (2005) examined the detrimental effect of part-list cues in first graders, fourth graders, and young adults. All three groups showed reliable part-list cuing impairment with no difference in amount of forgetting across the three age groups. Moreover, in this experiment, part-list cuing impairment was directly compared with retrieval-induced forgetting. None of the three age groups showed any reliable difference between the detrimental effect of retrieval practice and the detrimental effect of part-list cuing.

In older adults, Marsh et al. (2004) found robust part-list cuing impairment in both younger and older adults across three experiments. If anything, the older adults showed stronger detrimental effects than the young adults and were disproportionately slow in the presence of part-list cues. This result suggests that part-list cuing impairment is not reduced in older adults. Part-list cuing impairment, like retrieval-induced forgetting, thus may be intact across most of the lifespan.

#### 2.13.2.6.4 Summary

To date, relatively few studies have addressed the development of inhibition in human memory. From these studies a fair amount of knowledge has been gained regarding the development of inhibitory mechanisms as they occur in retrieval-induced forgetting, directed forgetting, and part-list cuing impairment. Unfortunately, there are no published studies to date in which the development of inhibitory processes involved in strength-induced forgetting and think/no-think impairment has been addressed, so that the current picture on the development of inhibition in memory is only fragmentary.

Still, current results clearly challenge the hypothesis of a general inhibitory deficit in young children and older adults by showing that both age groups show intact inhibition in some memory tasks. It thus seems that the picture of a general inhibitory deficit needs to be updated in favor of the picture of task-dependent inhibitory function. Specifying the exact nature of the inhibitory mechanisms that are intact in young children and older adults and of those that are deficient is a high priority for future research on the development of inhibitory function.

## 2.13.3 Conclusions

In the introduction, three inhibitory mechanisms were suggested to reduce accessibility of irrelevant memories: blocking, route deactivation, and item suppression (**Figure 1**). These mechanisms differ in whether they affect memories indirectly (blocking) or directly (route deactivation, item suppression), and whether they affect memories' retrieval routes (route deactivation) or their representation itself (item suppression). As a result, the three mechanisms also differ in the range of memory tests in which the effects of inhibition can be observed. While effects of blocking manifest themselves mainly in free-recall tests and effects of route deactivation in free- and cued-recall tests, effects of item suppression are present over a wide range of memory tasks, including recognition and independent-probe tests.

The results on the experimental paradigms reviewed in section 2.13.2 suggest that each of the three mechanisms plays a role in reducing irrelevant memories' accessibility. However, the results also suggest that none of the three mechanisms is responsible for the effects in all the paradigms. Rather, it seems that a multiplicity of mechanisms are at work to induce inaccessibility of irrelevant material across a wide range of situations. In strength-induced forgetting, for instance, inhibition seems to be realized by means of blocking, in which early recall of strengthened (relevant) material hinders subsequent recall of nonstrengthened (irrelevant) material. Consistently, forgetting is present mainly in free recall tasks and is absent in recognition tasks. Strength-induced forgetting thus is mediated by a relatively weak form of inhibition that affects the irrelevant material only indirectly. The same mechanism is likely to be involved in item-method directed forgetting, at least when following the strengthening view of this form of directed forgetting.

In list-method directed forgetting, a stronger form of inhibition is at work in which the retrieval routes between the irrelevant material and its cue(s) are affected directly. Accordingly, forgetting in this paradigm can be observed in free and cued recall tasks while no effects arise in recognition tests, which rely mainly on the items' representation itself. In strength-induced forgetting, the effects on the relevant and irrelevant material's accessibility are mediated by the same mechanism. In list-method directed forgetting, there is evidence for two separate processes, one process reducing accessibility of the irrelevant material and the other process enhancing accessibility of the relevant information. When operating in concert, these two processes can create very effective memory updating.

In retrieval-induced forgetting, inhibition is realized by suppressing the representation of the inhibited items themselves, thus making retrieval less effective regardless of which retrieval cue is employed. Consistent with this strong form of inhibition, the forgetting in this paradigm can be found across a wide range of memory tests, including recognition and independent probe tests. As in list-method directed forgetting, there is evidence for the action of two processes, a forgetting mechanism directed on the irrelevant material and an enhancement mechanism directed on the relevant information. Together, they induce a strong difference in accessibility between relevant and irrelevant material and thus induce effective memory updating. There is also evidence that the same inhibitory mechanism underlies the forgetting in the think/no-think paradigm and in part-list cuing, because in both cases the forgetting has been found not only to arise in free- and cued-recall tasks but to generalize to other tasks as well.

The evidence that different mechanisms mediate inhibition in the single paradigms motivates a taxonomy of the paradigms, in which the paradigms are partitioned into three subsets, one in which the forgetting is caused by blocking (strength-induced forgetting, possibly item-method directed forgetting), one in which the forgetting is caused by route deactivation (list-method directed forgetting), and one in which the forgetting is caused by item suppression (retrieval-induced forgetting, think/no-think impairment, and part-list cuing impairment; **Figure 8**). Although currently there is only restricted knowledge regarding the developmental aspects of inhibition in the single paradigms, the suggested taxonomy is at least consistent with current knowledge. Current knowledge suggests comparable developmental trajectories for retrieval-induced forgetting and part-list cuing impairment and a different trajectory for list-method directed forgetting. Item suppression and route deactivation thus may follow different developmental paths.

Besides the differences in underlying mechanism, the single paradigms also differ regarding the stage at which the inhibition takes place. In list-method directed forgetting, inhibition operates before the test during the encoding of the new relevant material. In retrieval-induced forgetting and think/no-think impairment, inhibition also operates before the test, either while selectively retrieving relevant information (retrieval-induced forgetting) or while trying to stop retrieval of irrelevant information (think/no-think impairment). In strength-induced forgetting, item-method directed forgetting, and part-list cuing impairment, the inhibition operates at test, either by blocking recall of irrelevant material (strength-induced forgetting, item-method directed forgetting) or by suppressing relevant material through covert retrieval of cue items (part-list cuing impairment).

It is the general goal of inhibition in memory to enhance accessibility of relevant material at the expense of the accessibility of the irrelevant material. This goal is realized very differently in different situations. The differences are reflected in the

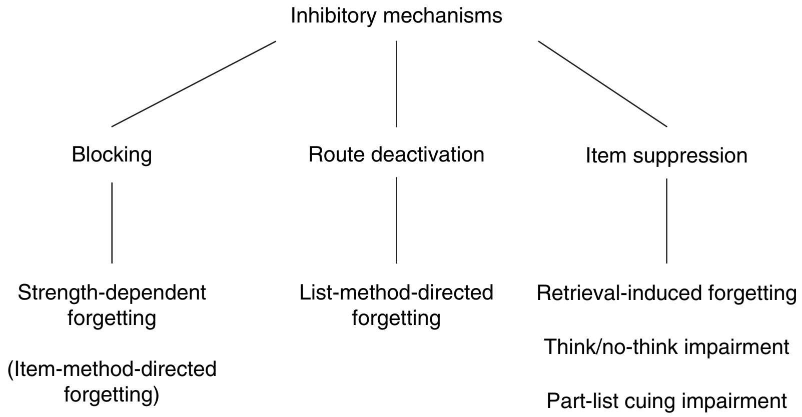


**Figure 8** Taxonomy of inhibition paradigms. The taxonomy lists experimental paradigms in which some form of inhibitory mechanism is assumed to be crucially involved. The paradigms are partitioned according to which of the three mechanisms – blocking, route deactivation, and item suppression (**Figure 1**) – is supposed to mediate the inhibition.

diversity of mechanisms that mediate the effect in the single situations, and they are reflected in the varying stages at which the inhibition takes place. Together, the picture of a very flexible and goal-directed updating system arises, in which a multiplicity of inhibitory mechanisms operate at very different processing stages to overcome the problem of retrieval competition and interference and thus help memory function effectively. At the end of the nineteenth century, Ribot wrote that "Forgetfulness . . . is not a disease of memory, but a condition of its health and life" (Ribot, 1882: 61). The results reviewed in this chapter provide a vivid and detailed demonstration of the adequacy of this early view.

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## References

Anderson JR and Schooler LJ (1991) Reflections of the environment in memory. *Psychol. Sci.* 2: 396–408.
Anderson MC (2003) Rethinking interference theory: Executive control and the mechanisms of forgetting. *J. Mem. Lang.* 49: 415–445.
Anderson MC and Green C (2001) Suppressing unwanted memories by executive control. *Nature* 410: 366–369.
Anderson MC and Spellman BA (1995) On the status of inhibitory mechanisms in cognition: Memory retrieval as a model case. *Psychol. Rev.* 102: 68–100.
Anderson MC, Bjork RA, and Bjork EL (1994) Remembering can cause forgetting: Retrieval dynamics in long-term memory. *J. Exp. Psychol. Learn.* 20: 1063–1087.
Anderson MC, Bjork EL, and Bjork RA (2000a) Retrieval-induced forgetting: Evidence for a recall-specific mechanism. *Psychon. B Rev.* 7: 522–530.
Anderson MC, Green C, and McCulloch KC (2000b) Similarity and inhibition in long-term memory: Evidence for a two-factor theory. *J. Exp. Psychol. Learn.* 26: 1141–1159.
Anderson MC, Ochsner KN, Kuhl B, et al. (2004) Neural systems underlying the suppression of unwanted memories. *Science* 30: 3: 232–235.
Aslan A and Bäuml K-H (in press) Part-list cuing with and without item-specific probes: The role of encoding. *Psychon. B Rev. Learn. Cogn.* 32: 33–43.
Aslan A, Bäuml K-H, and Grundgeiger T (2007a) The role of inhibitory processes in part-list cuing. *J. Exp. Psychol. Learn.* 33: 335–341.
Aslan A, Bäuml K-H, and Pastötter B (2007b) No inhibitory deficit in older adults' episodic memory. *Psychol. Sci.* 18: 72–78.
Basden DR and Basden BH (1995) Some tests of the strategy disruption interpretation of part-list cuing inhibition. *J. Exp. Psychol. Learn.* 21: 1656–1669.
Basden BH and Basden DR (1996) Directed forgetting: Further comparisons of the item and list methods. *Memory* 4: 633–653.
Basden BH, Basden DR, and Gargano GJ (1993) Directed forgetting in implicit and explicit memory tests: A comparison of methods. *J. Exp. Psychol. Learn.* 19: 603–616.
Basden BH, Basden DR, and Wright MJ (2003) Part-list reexposure and release of retrieval inhibition. *Consc. Cogn.* 12: 354–375.
Bäuml K-H (1996) Revisiting an old issue: Retroactive interference as a function of the degree of original and interpolated learning. *Psychon. B Rev.* 3: 380–384.
Bäuml K-H (1997) The list-strength effect: Strength-dependent competition or suppression? *Psychon. B Rev.* 4: 260–264.
Bäuml K-H (1998) Strong items get suppressed, weak items do not: the role of item strength in output interference. *Psychon. B Rev.* 5: 459–463.
Bäuml K-H (2002) Semantic generation can cause episodic forgetting. *Psychol. Sci.* 13: 357–361.
Bäuml K-H and Aslan A (2004) Part-list cuing as instructed retrieval inhibition. *Mem. Cogn.* 32: 610–617.

Bäuml K-H and Aslan A (2006) Part-list cuing can be transient and lasting: The role of encoding. *J. Exp. Psychol. Learn.* 32: 33–43.
Bäuml K-H and Hartinger A (2002) On the role of item similarity in retrieval-induced forgetting. *Memory* 10: 215–224.
Bäuml K-H and Kuhbandner C (2003) Retrieval-induced forgetting and part-list cuing in associatively structured lists. *Mem. Cogn.* 31: 1188–1197.
Bäuml K-H and Kuhbandner C (2007) Remembering can cause forgetting – But not in negative moods. *Psychol. Sci.* 18: 111–115.
Bäuml K-H, Kissler J, and Rak A (2002) Part-list cuing in amnesic patients: Evidence for a retrieval deficit. *Mem. Cogn.* 30: 862–870.
Bäuml K-H, Zellner M, and Vilimek R (2005) When remembering causes forgetting: Retrieval-induced forgetting as recovery failure. *J. Exp. Psychol. Learn.* 31: 1221–1234.
Benjamin AS (2007) The effects of list-method directed forgetting on recognition memory. *Psychon. B Rev.* 13: 831–836.
Bjork EL and Bjork RA (1996) Continuing influences of to-be-forgotten information. *Conscious. Cogn.* 5: 176–196.
Bjork EL, Bjork RA, and Glenberg AM (1973) The reinstatement of interference owing to to-be-forgotten items. Paper presented at the Annual Meeting of the Psychonomic Society St. Louis MO, November 1973.
Bjork RA (1970) Positive forgetting: The noninterference of items intentionally forgotten. *J. Verb. Learn. Verb. Behav.* 9: 255–268.
Bjork RA (1972) Theoretical implications of directed forgetting. In: Melton AW and Martin E (eds.) *Coding Processes in Human Memory*, pp. 217–235. Winston: Washington DC.
Bjork RA (1989) Retrieval inhibition as an adaptive mechanism in human memory. In: Roediger HL III and Craik FIM (eds.) Varieties of Memory and Consciousness: Essays in Honour of Endel Tulving, pp. 309–330. Hillsdale, NJ: Lawrence Erlbaum Associates.
Bjorklund DF and Harnishfeger KK (1990) The resources construct in cognitive development: Diverse sources of evidence and a theory of inefficient inhibition. *Dev. Rev.* 10: 48–71.
Bray NW, Justice EM, and Zahm DN (1983) Two developmental transitions in selective remembering strategies. *J. Exp. Child Psychol.* 36: 43–55.
Bulevich JB, Roediger HL III, Balota DA, and Butler AC (2006) Failure to find suppression of episodic memories in the think/no-think paradigm. *Mem. Cogn.* 34: 1569–1577.
Camp G, Pecher D, and Schmidt HG (2005) Retrieval-induced forgetting in implicit memory tests: The role of test awareness. *Psychon. B Rev.* 12: 490–494.
Carrier M and Pashler H (1992) The influence of retrieval on retention. *Mem. Cogn.* 20: 633–642.
Chan JCK, McDermott KB, and Roediger HL III (2006) Retrieval-induced facilitation: Initially nontested material can benefit from prior testing of related material. *J. Exp. Psychol. Gen.* 135: 553–571.
Ciranni MA and Shimamura AP (1999) Retrieval-induced forgetting in episodic memory. *J. Exp. Psychol. Learn.* 25: 1403–1414.
Conroy R and Salmon K (2005) Selective postevent review and children's memory for nonreviewed materials. *J. Exp. Child Psychol.* 90: 185–207.
Conway MA, Harries K, Noyes J, Racsmany M, and Frankish CR (2000) The disruption and dissolution of directed forgetting: Inhibitory control of memory. *J. Mem. Lang.* 43: 409–430.
Crowder RG (1976) *Principles of Learning and Memory*. New York: John Wiley & Sons.
DaPolito FJ (1966) *Proactive Effects with Independent Retrieval of Competing Responses.* PhD Thesis. Indiana University.
Davis JC and Okada R (1971) Recognition and recall of positively forgotten items. *J. Exp. Psychol.* 89: 181–186.
Delprado DJ (2005) Retroactive interference as a function of degree of interpolated study without overt retrieval practice. *Psychon. B Rev.* 12: 345–349.
Depue BE, Banich MT, and Curran T (2006) Suppression of emotional and nonemotional content in memory. *Psychol. Sci.* 17: 441–447.
Dulaney CL, Marks W, and Link KE (2004) Aging and directed forgetting: Precue encoding and postcue rehearsal effects. *Exp. Aging Res.* 30: 95–112.
Earles JL and Kersten AW (2002) Directed forgetting of actions by younger and older adults. *Psychon. B Rev.* 9: 383–388.
Ford RM, Keating S, and Patel R (2004) Retrieval-induced forgetting: A developmental study. *Br. J. Dev. Psychol.* 22: 585–603.
Foster RN and Gavelek JR (1983) Development of intentional forgetting in normal and reading-delayed children. *J. Educ. Psychol.* 75: 431–440.
Gardiner JM, Gawlik G, and Richardson-Klavehn A (1994) Maintenance rehearsal affects knowing not remembering: Elaborative rehearsal affects remembering not knowing. *Psychon. B Rev.* 1: 107–110.
Geiselman RE, Bjork RA, and Fishman D (1983) Disrupted retrieval in directed forgetting: A link with posthypnotic amnesia. *J. Exp. Psychol. Gen.* 112: 58–72.
Gelfand H and Bjork RA (1985) On the locus of retrieval inhibition in directed forgetting. Paper presented at the 26th annual meeting of the Psychonomic Society, Boston MA.
Goernert PN and Larson ME (1994) The initiation and release of retrieval inhibition. *J. Gen. Psychol.* 121: 61–66.
Gómez-Ariza CJ, Lechuga MT, Pelegrina S, and Bajo MT (2005) Retrieval-induced forgetting in recall and recognition of thematically related and unrelated sentences. *Mem. Cogn.* 33: 1431–1441.
Harnishfeger KK and Pope RS (1996) Intending to forget: The development of cognitive inhibition in directed forgetting. *J. Exp. Child Psychol.* 62: 292–315.
Hartman M and Hasher L (1991) Aging and suppression: Memory for previously relevant information. *Psychol. Aging* 6: 587–594.
Hasher L and Zacks RT (1988) Working memory, comprehension, and aging: A review and a new view. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory*, vol. 22. pp. 193–225. San Diego: Academic Press.
Hasher L, Quig MB, and May CP (1997) Inhibitory control over no-longer-relevant information: Adult age differences. *Mem. Cogn.* 25: 286–295.
Hayne H, Garry M, and Loftus EF (2006) On the continuing lack of scientific evidence for repression. *Behav. Brain Sci.* 29: 521–533.
Hertel PT and Calcaterra G (2005) Intentional forgetting benefits from thought substitution. *Psychon. B Rev.* 12: 484–489.
Hicks JL and Starns J (2004) Retrieval-induced forgetting occurs in tests of item recognition. *Psychon. B Rev.* 11: 125–130.
Hogan RM and Kintsch W (1971) Differential effects of study and test trials on long-term recognition and recall. *J. Verb. Learn. Verb. Behav.* 10: 562–567.
Hunt R and McDaniel M (1993) The enigma of organization and distinctiveness. *J. Mem. Lang.* 32: 421–445.
Jacoby LL (1991) A process dissociation framework: Separating automatic from intentional uses of memory. *J. Mem. Lang.* 30: 513–541.
Johansson M, Aslan A, Bäuml K-H, Gäbel A, and Mecklinger A (2007) When remembering causes forgetting: electrophysiological correlates of retrieval-induced forgetting. *Cereb. Cortex* 17: 1335–1341.

Koutstaal W, Schacter DL, Johnson MK, and Galluccio L (1999) Facilitation and impairment of event memory produced by photograph review. *Mem. Cogn.* 27: 478–493.

Lechuga MA, Moreno V, Pelegrina S, Gómez-Ariza CJ, and Bajo MT (2006) Age differences in memory control: Evidence from updating and retrieval-practice tasks. *Acta. Psychol. (Amst.)* 123: 279–298.

MacLeod CM (1989) Directed forgetting affects both direct and indirect tests of memory. *J. Exp. Psychol. Learn.* 15: 13–21.

MacLeod CM (1998) Directed forgetting. In: Golding JM and MacLeod CM (eds.) *Intentional Forgetting: Interdisciplinary Approaches*, pp. 1–57. Mahwah NJ: Erlbaum.

MacLeod CM (1999) The item and list methods of directed forgetting: Test differences and the role of demand characteristics. *Psychon. B Rev.* 6: 123–129.

MacLeod CM and Daniels KA (2000) Direct versus indirect tests of memory: Directed forgetting meets the generation effect. *Psychon. B Rev.* 7: 354–359.

MacLeod MD and Macrae CN (2001) Gone but not forgotten: The transient nature of retrieval-induced forgetting. *Psychol. Sci.* 12: 148–152.

Macrae CN and MacLeod MD (1999) On recollections lost: When practice makes imperfect. *J. Pers. Soc. Psychol.* 77: 463–473.

Macrae CN, Bodenhausen GV, Milne AB, and Ford RL (1997) On the regulation of recollection. The intentional forgetting of stereotypical memories. *J. Pers. Soc. Psychol.* 72: 709–719.

Malmberg KJ and Shiffrin RM (2005) The one-shot hypothesis for context storage. *J. Exp. Psychol. Learn.* 31: 322–336.

Marsh EJ, Dolan PO, Balota DA, and Roediger HL III (2004) Part-set cuing effects younger and older adults. *Psychol. Aging* 19: 134–144.

McGeoch JA (1942) The psychology of human learning: An introduction. New York: Longmans.

Melton AW and Irwin JM (1940) The influence of degree of interpolated learning on retroactive inhibition and the overt transfer of specific factors. *Am. J. Psychol.* 3: 173–203.

Mensink J-G and Raaijmakers JGW (1988) A model of interference and forgetting. *Psychol. Rev.* 95: 434–455.

Moulin CJA, Perfect TJ, Conway MA, North A, Jones RW, and James AN (2002) Retrieval-induced forgetting in Alzheimer's disease. *Neuropsychologia* 40: 862–867.

Müller GE and Pilzecker A (1900) Experimentelle Beiträge zur Lehre vom Gedächtnis. *Z Psychol.* 1: 1–300.

Murnane K and Shiffrin RM (1991) Interference and the representation of events in memory. *J. Exp. Psychol. Learn.* 17: 855–874.

Neely JH, Schmidt SR, and Roediger HL III (1983) Inhibition from related primes in recognition memory. *J. Exp. Psychol. Learn.* 9: 196–211.

Nickerson RS (1984) Retrieval inhibition from part-set cuing: A persisting enigma in memory research. *Mem. Cogn.* 12: 531–552.

Norman KA (2002) Differential effects of list strength on recollection and familiarity. *J. Exp. Psychol. Learn.* 28: 1083–1094.

Oswald KM, Serra M, and Krishna A (2006) Part-list cuing in speeded recognition and free recall. *Mem. Cogn.* 34: 518–526.

Pastötter B and Bäuml K-H (in press) The crucial role of post-cue encoding in directed forgetting and context-dependent forgetting. *J. Exp. Psychol. Learn.*

Perfect TJ, Moulin CJA, Conway MA, and Perry E (2002) Assessing the inhibitory account of retrieval-induced forgetting with implicit-memory tests. *J. Exp. Psychol. Learn.* 28: 1111–1119.

Perfect TJ, Stark L-J, Tree JJ, Moulin CJA, Ahmed L, and Hutter R (2004) Transfer appropriate forgetting: The cue-dependent nature of retrieval-induced forgetting. *J. Mem. Lang.* 51: 399–417.

Posnansky CJ (1976) Directed forgetting among third and seventh graders. *Contemp. Educ. Psychol.* 1: 247–256.

Postman L, Stark K, and Fraser J (1968) Temporal changes in interference. *J. Verb. Learn. Verb. Behav.* 7: 672–694.

Raaijmakers JGW and Shiffrin RM (1981) Search of associative memory. *Psychol. Rev.* 88: 93–134.

Racsmany M and Conway MA (2006) Episodic inhibition. *J. Exp. Psychol. Learn.* 32: 44–57.

Ratcliff R, Clark SE, and Shiffrin RM (1990) List-strength effect: I. Data and discussion. *J. Exp. Psychol. Learn.* 16: 163–178.

Ratcliff R, Sheu C-F, and Gronlund SD (1992) Testing global memory models using ROC curves. *Psychol. Rev.* 99: 518–535.

Ribot TA (1882) *Diseases of Memory: An Essay in the Positive Psychology*. New York: Appleton-Century-Crofts.

Roediger HL III (1973) Inhibition in recall from cueing with recall targets. *J. Verb. Learn. Verb. Behav.* 12: 644–657.

Roediger HL III (1974) Inhibiting effects of recall. *Mem. Cogn.* 2: 261–269.

Roediger HL III (1978) Recall as a self-limiting process. *Mem. Cogn.* 6: 54–63.

Roediger HL III and Karpicke JD (2006) Test-enhanced learning: Taking memory tests improves long-term retention. *Psychol. Sci.* 17: 249–255.

Roediger HL III and Neely JH (1982) Retrieval blocks in episodic and semantic memory. *Can. J. Psychol.* 36: 213–242.

Roediger HL III and Schmidt SR (1980) Output interference in the recall of categorized and paired associate lists. *J. Exp. Psychol. Learn.* 6: 91–105.

Rohrer D (1996) On the relative and absolute strength of a memory trace. *Mem. Cogn.* 24: 188–201.

Rundus D (1973) Negative effects of using list items as recall cues. *J. Verb. Learn. Verb. Behav.* 12: 43–50.

Sahakyan L and Delaney PF (2003) Can encoding differences explain the benefits of directed forgetting in the list method paradigm? *J. Mem. Lang.* 48: 195–206.

Sahakyan L and Delaney PF (2005) Directed forgetting in incidental learning and recognition testing: Support for a two-factor account. *J. Exp. Psychol. Learn.* 31: 789–801.

Sahakyan L and Kelley CM (2002) A contextual change account of the directed forgetting effect. *J. Exp. Psychol. Learn.* 28: 1064–1072.

Saunders J and MacLeod MD (2006) Can inhibition resolve retrieval competition through the control of spreading activation? *Mem. Cogn.* 34: 307–322.

Sego SA, Golding JM, and Gottlob LR (2006) Directed forgetting in older adults using the item and list method. *Aging Neuropsychol. Cogn.* 13: 95–114.

Simpson GB and Foster MR (1986) Lexical ambiguity and children's word recognition. *Dev. Psychol.* 22: 147–154.

Slamecka NJ (1968) An examination of trace storage in free recall. *J. Exp. Psychol.* 76: 504–513.

Smith AD (1971) Output interference and organized recall from long-term memory. *J. Verb. Learn. Verb. Behav.* 10: 400–408.

Smith RE and Hunt RR (2000) The influence of distinctive processing on retrieval-induced forgetting. *Mem. Cogn.* 28: 503–508.

Spitzer B and Bäuml K-H (in press) Retrieval-induced forgetting in item recognition: Evidence for a reduction in general memory strength. *J. Exp. Psychol. Learn.*

Storbeck J and Clore GL (2005) With sadness comes accuracy; with happiness, false memory. *Psychol. Sci.* 16: 785–791.

Szpunar KK, McDermott KB, Roediger HL III (in press) Expectation of a final cumulative test enhances long-term retention. *Mem. Cogn*.

Tipper SP, Bourque TA, Anderson SH, and Brehaut J (1989) Mechanisms of attention: A developmental study. *J. Exp. Child Psychol.* 48: 353–378.

Todres AK and Watkins MJ (1981) A part-set cuing effect in recognition memory. *J. Exp. Psychol. Learn.* 7: 91–99.
Tulving E (1974) Cue-dependent forgetting. *Am. Sci.* 62: 74–82.
Tulving E (1985) Memory and consciousness. *Can. Psychol.* 26: 1–12.
Tulving E and Hastie R (1972) Inhibition effects of intralist repetition in free recall. *J. Exp. Psychol.* 92: 297–304.
Tulving E and Pearlstone Z (1966) Availability versus accessibility of information in memory for words. *J. Verb. Learn. Verb. Behav.* 5: 381–391.
Tulving E and Psotka J (1971) Retroactive inhibition in free recall: Inaccessibility of information available in the memory store. *J. Exp. Psychol.* 87: 1–8.
Underwood BJ (1957) Interference and forgetting. *Psychol. Rev.* 64: 49–60.
Veling H and van Knippenberg A (2004) Remembering can cause inhibition: Retrieval-induced inhibition as cue independent process. *J. Exp. Psychol. Learn.* 30: 315–318.
Verde MF (2004) The retrieval practice effect in associative recognition. *Mem. Cogn.* 32: 1265–1272.
Verde MF and Rotello CM (2004) Strong memories obscure weak memories in associative recognition. *Psychon. B Rev.* 11: 1062–1066.
Watkins MJ (1975) Inhibition in recall with extralist ‘‘cues’’. *J. Verb. Learn. Verb. Behav.* 14: 294–303.
Weiner B and Reed H (1969) Effects of the instructional sets to remember and to forget on short-term retention: Studies of rehearsal control and retrieval inhibition (repression). *J. Exp. Psychol.* 79: 225–232.
Williams CC and Zacks RT (2001) Is retrieval-induced forgetting an inhibitory process? *Am. J. Psychol.* 114: 329–354.
Williams S-J, Wright DB, and Freeman NH (2002) Inhibiting children's memory of an interactive event: The effectiveness of a cover-up. *App. Cogn. Psychol.* 16: 651–664.
Wixted JT and Rohrer D (1994) Analyzing the dynamics of free recall: An integrative review of the empirical literature. *Psychon. B Rev.* 1: 89–106.
Wixted JT, Ghadisha H, and Vera R (1997) Recall latency following pure- and mixed-strength lists: A direct test of the relative strength model of free recall. *J. Exp. Psychol. Learn.* 23: 523–538.
Woodward AE Jr and Bjork RA (1971) Forgetting and remembering in free recall: Intentional and unintentional. *J. Exp. Psychol.* 89: 109–116.
Yonelinas AP (2002) The nature of recollection and familiarity: A review of 30 years of research. *J. Mem. Lang.* 46: 441–517.
Zacks RT, Radvansky GA, and Hasher L (1996) Studies of directed forgetting in older adults. *J. Exp. Psychol. Learn.* 22: 143–156.
Zellner M and Bäuml K-H (2005) Intact retrieval inhibition in children's episodic recall. *Mem. Cogn.* 33: 396–404.
Zellner M and Bäuml K-H (2006) Inhibitory deficits in older adults – List-method directed forgetting revisited. *J. Exp. Psychol. Learn.* 32: 290–300.

# 2.14 False Memories

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Memory is impressive. People can recognize hundreds of pictures seen only once (Shepard, 1967) and recall hundreds of words in response to cues (Mäntylä, 1986). Memory's feats are not limited to short delays or to remembering simple materials in laboratory settings. People remember their high school classmates 15 years after graduation (Bahrick et al., 1975) and recall details about the German invasion of Denmark 50 years after they experienced it (Berntsen and Thomsen, 2005). This short list could easily be expanded.

And yet memory's failures can be equally impressive. For example, people's recognition memory for a penny is actually quite poor, even though they have likely handled hundreds (if not thousands) over the years (Nickerson and Adams, 1979). Similarly, the majority of people fail when asked to draw the layout of the number keys on a calculator, even though they could easily use such a device (Rinck, 1999). Memory failures are not limited to mundane objects, of course. Consider just a few examples: Parents misremember the way they raised their children (Robbins, 1963), eyewitness misidentifications occur (Wells et al., 2006), and people falsely remember being abducted by aliens (Clancy, 2005).

To understand human memory, we must understand memory's failures as well as its successes. What is more interesting than the fact that memory is fallible is that the errors are systematic. By systematic, we simply mean that the errors are not random. We understand something about the conditions under which errors are more or less likely; for example, delay is a manipulation that often increases memory errors. This systematicity occurs because errors are often byproducts of mechanisms that normally aid memory, meaning that memory errors can provide a window into the mechanisms of memory.

One of the classics in this tradition is Bartlett's 1932 study in which participants read and retold a Native American story entitled 'The War of the Ghosts.' When participants retold the story, they made systematic errors. They changed the unfamiliar Native American tale so that it made more sense to them and so that it fit better with their English culture. For example, in the retellings 'canoe' became 'boat' and the more supernatural parts of the story either disappeared or changed to be more consistent with a typical English story.

Bartlett concluded that our memories are reconstructive. We do not recall exactly what happened; rather, we reconstruct events using our knowledge, culture, and prior beliefs about what must have occurred. In other words, we use schemas to help reconstruct our memories. A schema is a knowledge structure that organizes what one knows and expects about some aspect of the world. Schemas are useful heuristics that allow us to fill in the gaps and to make predictions. Bartlett's participants possessed a schema about what happens in a typical story and they used this schema to reconstruct the atypical story that they had read.

Bartlett's ideas about reconstructive memory and the influence of one's prior knowledge have been modified only slightly through the years and are still thought to be the backbone of how our memory functions. Schemas have been repeatedly shown to have large effects on later memory. For example, consider a classic study in which participants read short passages, including one about an unruly child.

When told that the story was about Helen Keller, participants later falsely recognized sentences such as 'She was deaf, dumb, and blind.' When the protagonist was labeled as Carol Harris, however, participants rarely falsely recognized the same sentences (Dooling and Christiaansen, 1977). The familiar label presumably activated participants' prior knowledge of Helen Keller, which participants used to make sense of the passage and to fill in gaps in the story. One's schema of Helen Keller, for example, might include information about her childhood in Alabama and her disabilities, as well as how she blossomed into a successful speaker and writer with the help of her teacher Anne Sullivan. While this background knowledge is likely to aid comprehension of the passage, it also sets up the need to later discriminate between what was read in the passage versus what was inferred.

Schemas provide one example of a memory mechanism that can both help and hurt memory. Most of the time, schemas support accurate memory; however, in some instances (such as the Helen Keller example), they can lead us astray. In this chapter, we will consider several different memory mechanisms that, like schemas, can sometimes lead our memories astray. We will focus on memory errors that meet Roediger's (1996) definition of memory illusions. Specifically, the focus will be on "cases in which a rememberer's report of a past event seriously deviates from the event's actual occurrence" (Roediger, 1996: 76). We will place a particular emphasis on memory errors that are made with high confidence, are labeled as remembered, or otherwise appear phenomenologically real. To preview a few of the vivid memory errors we will discuss: they include high-confidence errors in eyewitness testimony, never-presented words 'remembered' as spoken by a specific person, and ease of processing mistaken for fame. In each case, we will describe a prototypical experiment and the results and discuss possible underlying mechanisms.

## 2.14.1 False Memory for Words: The Deese-Roediger-McDermott Paradigm

As already described, Bartlett emphasized the use of meaningful materials when examining reconstructive memory, to avoid studying memory that was "primarily or literally reduplicative, or reproductive ... I discarded nonsense material because, among other difficulties, its use almost always weights the evidence in favor of mere rote recapitulation, and for the most part I used exactly the type of material that we have to deal with in daily life" (Bartlett, 1932: 204). Consistent with Bartlett's ideas, most of the studies we will describe in this chapter involve remembering videos, stories, slide shows, or personal memories. While words and nonsense syllables were frequently used in verbal learning experiments, Bartlett did not believe they would be useful in studying reconstructive memory since they did not encourage elaboration nor the use of schemas.

However, words have many properties that make them handy tools for the experimental psychologist. Tulving (1983) has made this argument eloquently: "words to the memory researcher are what fruit flies are to the geneticist: a convenient medium through which the phenomena and processes of interest can be explored and elucidated... words are of no more intrinsic interest to the student of memory than *Drosophila* are to a scientist probing the mechanisms of heredity" (Tulving, 1983: 146). Tulving goes on to point out that words have well-defined boundaries and are easily perceived, and that memories for words can easily be checked for accuracy. The point is that using word stimuli to study false memories would be very useful, if word stimuli could be selected that would encourage elaboration and the use of schemas. The argument is that the Deese-Roediger-McDermott (DRM) stimuli fit these requirements, and allow a simple and robust paradigm for studying false memories.

In a typical DRM experiment, participants learn lists of words, each related to a central nonpresented word, the critical lure. For example, participants hear or see 'nurse, sick, lawyer, medicine, health, hospital, dentist, physician, ill, patient, office, stethoscope, surgeon, clinic, cure.' Even though the critical lure 'doctor' was never presented, subjects are likely to include it when recalling the list items. They are also likely to incorrectly call it 'old' on a recognition memory test. The DRM paradigm appeals to experimenters because of the incredibly high rates of false memories observed in both free recall and on recognition measures. For example, in one of Roediger and McDermott's (1995) experiments, participants recalled the critical lures 55% of the time, a rate similar to recall of studied items presented in the middle of the list! False recognition was also very robust; Roediger and McDermott observed a false alarm rate of 76.5% for critical lures as compared to a hit rate of 72% for studied items. Similarly high levels of false memories have been observed in dozens, likely hundreds, of experiments using this methodology.

Not only are DRM errors frequent, they are also phenomenologically compelling to the rememberer. Roediger and McDermott asked participants to label each word called 'old' as either 'remembered' or 'known.' 'Remembering' was defined as vividly recollecting details associated with a word's presentation (e.g., where it occurred on the list, what it sounded like, what one was thinking during its presentation), whereas 'knowing' meant simply knowing a word had been presented even though one could not recall the details of its presentation. As shown in **Figure 1**, the proportion of remember and know responses was very similar for the studied words and for the critical lures (Roediger and McDermott, 1995). That is, people were just as likely to claim they remembered the critical nonpresented lures as the studied words. People will also describe their false memories in some detail, attributing them to locations in the study list (Read, 1996) and to a particular speaker (Payne et al., 1996). They are also willing to estimate how frequently they rehearsed each false memory (Brown et al., 2000). In general, the false memory effect is very robust, persisting even when participants have been forewarned about the nature of the illusion (McDermott and Roediger, 1998).

Given the strength of the illusion, it is intriguing that not all lists of related words yield false memories (Deese, 1959; Gallo and Roediger, 2002). Listening to 'sour, candy, sugar, bitter, good, taste, tooth, nice, honey, soda, chocolate, heart, cake, tart, pie' is likely to yield a false memory for 'sweet,' whereas listening

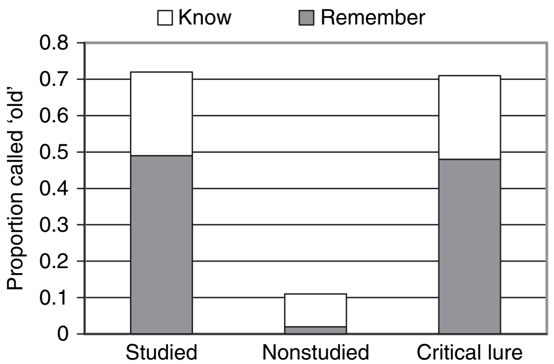


**Figure 1** Recognition results for studied items and critical lures. Data from Roediger HL III and McDermott KB (1995) Creating false memories: Remembering words not presented in lists. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 803–814, Experiment 2.

to 'sweet, sour, taste, chocolate, rice, cold, lemon, angry, hard, mad, acid, almonds, herbs, grape, fruit' is very unlikely to yield a false memory for the critical lure 'bitter.' Both lists were constructed from the same free-association norms, but only one yields high levels of false memories. A key difference between the lists involves backward associative strength (BAS); this is a measure of how likely the list items are to elicit the critical item in a free association task. In other words, BAS measures how likely participants are to report the critical lure as the first word that comes to mind in response to list items. Participants are likely to respond 'sweet' but not 'bitter' in response to words like 'sugar, sour, taste,' meaning that BAS is very high for 'sweet' but very low for 'bitter.' This difference is crucial; BAS is a major predictor of false recall ($r = 0.73$, Roediger et al., 2001b).

In the activation monitoring framework's explanation of the DRM illusion, activation at encoding spreads through a preexisting semantic network of words, and the source of this activation is monitored at test. Hearing 'sour, candy, sugar' in the study list activates those nodes in the network. This activation spreads through the network (Collins and Loftus, 1975), activating related nodes. Because the critical lure is associated with so many study items (as indicated by its BAS value), it is activated from many different directions, leading to its heightened activation. If the participant fails to correctly monitor the source of that activation, a false memory will result.

According to the activation monitoring framework, manipulations that increase the amount of activation spreading to the critical lure should result in higher rates of false memories. Consistent with this, false memories increase as the study list increases in length, as longer lists mean that activation from a greater number of words spreads to the critical lure (Robinson and Roediger, 1997). Similarly, activation can spread from phonological associates. Listening to a list of words like 'bite, fight, rut, sprite, slight, rye' yields false memories for phonologically related nonpresented words such as 'right' (Sommers and Lewis, 1999). Intriguingly, lists that combine phonological and semantic associates (e.g., 'bed, rest, awake, tired, dream, scrub, weep, wane, keep') led to even higher rates of false memories than did purely semantic or purely phonological lists (Watson et al., 2003).

Activation alone cannot, however, explain all of the data. An interesting experiment on the effects of presentation rate highlights the need for both activation and monitoring components. McDermott and Watson (2001) presented DRM lists at five different presentation rates: 20, 250, 1000, 3000, and 5000 ms per word. As expected, veridical recall of list items increased with longer presentation rates. More interesting were the false recall data. When the presentation rate increased from 20 to 250 ms, false recall increased from 0.14 to 0.31. However, when the presentation rate was further increased, the rate of false memories decreased, from 0.22 at 1000 ms to 0.14 at 3000 or 5000 ms. The argument is that semantic activation is increasing as the presentation rate increases, hence the jump in false memories observed at 250 ms. However, with the longer presentation rates, participants encode more information about studied words, allowing them to invoke monitoring strategies during retrieval that help them to judge the source of the activation.

Monitoring is necessary to explain other DRM data, such as the finding that on average older adults remember fewer studied words but falsely remember just as many critical lures (or even more) as do college students (e.g., Balota et al., 1999). That is, because older adults have relatively preserved semantic memory, there should not be age differences in the activation of the critical lure. Rather, what is affected is the ability to monitor the source of activation, as older adults typically have difficulty on source-monitoring tasks (Hashtroudi et al., 1989). More direct support for the monitoring explanation comes from a study linking the age effect to problems with frontal functioning (Butler et al., 2004). In this study, older adults were classified as high versus low functioning on tasks known to require frontal functioning (e.g., the Wisconsin card sort task). Importantly, older adults who scored high on frontal tasks performed similarly to young adults in a typical DRM paradigm. Only older adults who scored poorly on frontal tasks showed reduced true recall and increased false recall. Because frontal areas are often implicated in monitoring tasks (e.g., Raz, 2000), these data suggest it is monitoring ability, not age, that is critical for avoiding false memories.

Even young adults can be placed in situations that make monitoring difficult, forcing them to rely on activation. Consider Benjamin's (2001) study in which he repeatedly presented the DRM lists. Young adults were less likely to incorrectly endorse critical lures from lists presented three times, presumably because they were able to monitor the source of that activation. However, when participants were required to respond quickly at test, they falsely recognized more critical lures from the lists presented three times. Repeating the list presumably increased the activation of the critical lures. When time was plentiful during the recognition test, participants used monitoring processes to correctly attribute the source of the activation (and thus reduce, but not eliminate, the illusion). When retrieval time was short, monitoring was not possible, and the increased activation resulted in high false alarm rates (see also Marsh and Dolan, 2007).

The distinctiveness heuristic is one monitoring strategy that has been investigated in detail. Schacter and colleagues defined the distinctiveness heuristic as "a mode of responding based on participants' metamemorial awareness that true recognition of studied items should include recollection of distinctive details" (Schacter et al., 1999: 3). Anything that makes DRM stimuli more distinctive should increase participants' standards for what they consider to be old. Thus, picture lists yield lower rates of false memories than do word lists (Israel and Schacter, 1997), and pronouncing and hearing the words at study lowers the false alarm rate as compared to only hearing the words (Dodson and Schacter, 2001).

Activation monitoring is the preferred explanation of many researchers, but certainly not all. Other explanations share in common a mechanism for the lures being encoded, and then a monitoring function at test. For example, fuzzy trace theory (Brainerd and Reyna, 2002) proposes that both verbatim and gist traces are encoded for events. Verbatim traces reflect memories of individual events, while gist traces reflect the extraction of meaning across experienced events. During the presentation of a DRM list, verbatim traces would be encoded for the individual words, while at the same time the meaning of the entire list would be extracted and encoded into a gist memory. Later, retrieval of the gist trace could drive false memory effects.

We turn now from false memories of never-presented words to errors when remembering events such as crimes or traffic accidents. More important than the switch in what is being remembered, though, is that different memory mechanisms likely underlie the two types of errors.

## 2.14.2 Eyewitness Suggestibility: The Misinformation Paradigm

Psychologists have long been interested in the reliability of witnesses. Early in the twentieth century, researchers such as Hugo Münsterberg and William Stern were publishing on the unreliability of testimony. The major methodological breakthrough in this area, though, did not appear until the 1970s when Elizabeth Loftus published her seminal work. She developed the misinformation paradigm (also known as the post-event information paradigm) that involves a twist on the basic retroactive interference paradigms that were popular during the verbal learning era (McGeoch, 1932). In retroactive interference studies, researchers examine the effect of a second, interfering event on memory for an original event (as compared to a control group that was not exposed to the interference). The typical design is shown in the top part of **Table 1**. In verbal learning terms, all participants study paired associates A – B in the first phase of the experiment (e.g., Table – Radio). Next, participants in the experimental group learn A – D associations (e.g., Table – Pencil), whereas participants in the control group rest or learn C – D (e.g., Purse – Pencil). Finally, all participants are tested on A – B (e.g., Table – ?), and memory is poorer in the group that learned two different associations in response to A. What does this have to do with eyewitness memory? The bottom portion of **Table 1** shows the connection between the standard retroactive interference design and eyewitness memory. The witness views an event (A – B), such as a traffic accident (A) occurring near a stop sign (B). After the event, the police will repeatedly interview the witness, the newspaper will publish accounts of the crime, and the witness will talk about the event with other people. All these have the potential to provide interfering information. For example, the police might erroneously suggest that the accident (A) occurred near a yield sign (D) when really it occurred near a stop sign (B). Later, when the witness tries to remember the details of the original event (A – ?), he or she may recall the interfering misinformation instead of what was actually witnessed. In contrast, misinformation production would be low for subjects in a control condition who heard a neutral reference to a traffic sign.

One of the most classic laboratory demonstrations comes from Loftus et al. (1978; see also Loftus and Palmer, 1974). All participants viewed a slide show depicting a traffic accident; in the critical slide, a red Datsun was approaching an intersection with a traffic sign. One-half of participants saw a stop sign; the other participants saw exactly the same slide except that the intersection was marked with a yield sign. After seeing the slides, all participants answered a series of questions about the accident. Embedded in one of the questions was a reference to the traffic sign; half of participants were asked 'Did another car pass the red Datsun while it was stopped at the stop sign?' whereas the others answered 'Did another car pass the red Datsun while it was stopped at the yield sign?' Twenty minutes later, participants examined pairs of slides and determined which one had been presented in the original slide show. The critical pair required participants to pick between the Datsun at a stop sign versus a yield sign. When participants had answered the question containing misinformation, they selected the correct slide 41% of the time (below chance), as compared to 75% when the question had referred to the correct sign.

Numerous studies have since replicated the basic finding: Information presented after an event can change what the eyewitness remembers. The original event may take the form of a film, slide show, staged event, written story, or a real event. The misinformation may be delivered in the form of presuppositions in questions, suggestive statements, photographs (e.g., mugshots), or narrative summaries. It can come from the experimenter, a confederate, or the witness herself. The misinformation effect qualifies as a false

**Table 1** Experimental designs for studying retroactive interference (RI) and eyewitness suggestibility

| | *Condition* | *Study target (A – B)* | *Interference (A – D) or (C – D)* | *Test target (A – B)* |
|---|---|---|---|---|
| RI | | | | |
| | Experimental | Table – Radio | Table – Pencil | Table – ? |
| | Control | Table – Radio | Purse – Pencil | Table – ? |
| Eyewitness | | | | |
| | Misled | Accident – Stop sign | Accident – Yield sign | Accident – ? |
| | Control | Accident – Stop sign | Accident – Traffic sign | Accident – ? |

memory since participants generally endorse the misinformation quickly and with high confidence (Loftus et al., 1989). When participants described their erroneous memories, undergraduate judges were at chance at differentiating between real and suggested memories (Schooler et al., 1986).

One prerequisite for suggestibility is that participants fail to notice any problem with the misinformation when it is presented. This is called the discrepancy detection principle (Loftus, 1992). Participants are more likely to accept and reproduce misinformation about peripheral details than central characters or details (e.g., Christianson, 1992). In contrast, blatant misinformation not only is rejected, it also increases resistance to other peripheral misinformation (Loftus, 1979). Blatant misinformation may serve as a warning that the source is not to be trusted. This would be consistent with findings that warnings given before encoding of misinformation successfully reduce suggestibility, probably because warned participants read more slowly as they search for errors (Greene et al., 1982). In general, slow readers are more likely to notice (and resist) misinformation (Tousignant et al., 1986).

Given that participants do not detect the misinformation, manipulations that are generally known to enhance remembering lead to increased suggestibility, presumably because they increase memory for the misinformation. For example, suggestibility is greater if participants generate the misinformation (Roediger et al., 1996) and if the misinformation is repeated (Mitchell and Zaragoza, 1996; Zaragoza and Mitchell, 1996). Participants may also be more likely to rely on the misinformation if they have poor memory for the original events. For example, dividing attention during study (but not during the post-event information phase) increases suggestibility (Lane, 2006).

One important question is what happens to the original memory. It is easy to imagine the practical implications: If the original and post-event misinformation coexist in memory, it suggests the usefulness of developing strategies to help witnesses retrieve the original event. However, if the misinformation overwrites the original memory, it suggests that no retrieval strategy will allow access to the original event. Originally, there was much debate over this issue, but several lines of evidence suggest that the two memories may coexist. For example, consider what happens when misled participants are allowed to make a second guess after producing misinformation. If the original memories were completely unavailable, second-chance responses should be at chance (as what would they be based on?). Instead, second-chance guesses of misled participants are above chance (Wright et al., 1996), suggesting that some information about the original event is still available.

Compelling data for the coexistence hypothesis comes from experiments using source monitoring tests rather than recognition tests. Typically, in the 1970s and 1980s participants were required to make ‘old/new’ judgments about items. However, an ‘old’ judgment does not necessarily imply that participants remember seeing the misinformation in the original event. For example, participants may remember reading the misinformation in a post-event narrative and assume that remembering it from the narrative means it must have been in the video as well. To test these ideas, Lindsay and Johnson (1989) compared two groups of participants, all of whom studied the same photograph of an office. Afterward, half of participants read a narrative that mentioned eight office-related objects that were not actually in the original picture. Control participants read an accurate narrative description of the scene. The novel manipulation was at test; half of participants took a standard ‘yes/no’ recognition test, and half took a source monitoring test. For each item on the recognition test, participants indicated ‘yes’ if the object had been in the photograph and ‘no’ if it had not. On the source test, participants indicated whether each test object had been only in the picture, only in the text, in both the picture and the text, or in neither the picture nor the text. The results were dramatic: The misinformation effect was eliminated in the source condition! In later experiments, the advantage of the source test was replicated, although suggestibility was reduced rather than completely eliminated (Zaragoza and Lane, 1994).

Recent research on the misinformation effect has moved from the debate about the fate of the original memory trace to other interesting questions. One current trend is the examination of the effects of social context on suggestibility. This includes both the social context in which participants are exposed to misinformation, as well as the social context in which participants first intrude errors. For example, researchers are examining the effects of receiving misinformation from other people as opposed to reading it in narratives or embedded in questions (e.g., Roediger et al., 2001a; Gabbert et al., 2004; Wright et al., 2005). A related question involves the response the witness receives from other people after she (the witness) makes a mistake. The question of how feedback affects a witness’ memory is an important one, as incorrectly telling the witness 'Good, you identified the suspect' can have many negative consequences (see Douglass and Steblay, 2006, for a review; *See* Chapter 2.44).

## 2.14.3 Verbal Overshadowing

Rehearsal (especially elaborative rehearsal) can be a useful mnemonic for remembering word lists and prose. But what happens when a rehearsal fails to adequately capture the original experience? For example, words rarely capture the richness of our perceptions. What are the memorial consequences of a description (a rehearsal of sorts) that is inadequate or even inaccurate?

Questions about the effects of language and memory are not new ones. Many undergraduates are familiar with a classic study in which labels influenced memory for pictures. A picture of two circles joined by a line was labeled as either 'glasses' or 'barbell,' and participants later redrew the pictures to be similar to the label (Carmichael et al., 1932). In the 1970s, there was much interest in how participants integrated verbal and visual information in memory (e.g., Pezdek, 1977; Gentner and Loftus, 1979). Depending on the study, opposite conclusions were reached. Sometimes labeling pictures and objects led to enhanced memory (e.g., Santa and Ranken, 1972), but other times labeling was associated with difficulty on later memory tests (e.g., Gentner and Loftus, 1979).

More recently, Schooler and Engstler-Schooler (1990) sparked interest in the question by contextualizing it within the eyewitness memory domain. After watching a 30-s video of a bank robbery, participants in their Face Verbalization condition wrote a description of the thief's face (participants in the control condition did an unrelated task during that time). At test, all participants saw eight similar faces (including the thief) and were asked to select the perpetrator from the video or to indicate if he was absent from the line-up. The intriguing finding was that 64% of control participants selected the target, as compared to 37% in the face verbalization condition. Schooler and Engstler-Schooler labeled their finding verbal overshadowing.

Verbal overshadowing is not limited to faces; it extends to other types of perceptual information. Describing a voice reduces the ability to later identify that voice from among six options (Perfect et al., 2002). The typical wine drinker shows verbal overshadowing for wines, as they are unable to verbalize the nuances of wine in the vocabulary of experts (Melcher and Schooler, 1996). After memorizing a map of a small town, participants who wrote about it later performed worse on distance estimation tasks than did control participants (Fiore and Schooler, 2002). That is, having described one's spatial mental model of the town led to confusion about the distances between the landmarks.

Several different explanations have been proposed. One possibility involves recoding (*See* Chapter 2.07). Specifically, when participants describe a visual stimulus from memory, they are effectively recoding it from a visual representation to a verbal one, and the more recent recoded memory then interferes with the original visual memory. Consistent with an interference account, inserting a delay between the description and the final test reduces verbal overshadowing (Finger and Pezdek, 1999), in the same way that a delayed test can reduce retrieval blocking in other interference situations (e.g., Choi and Smith, 2005).

The recoding account would predict that the quality of the new verbal representation (as measured by the description) should predict the effects of verbalization on later memory tasks. Although Schooler and Engstler-Schooler (1990) did not find a relationship between the quality of the descriptions and the ability to recognize the perpetrator, this may be because of the way the descriptions were scored. Descriptions were considered better if they described more features of the target; however, this dependent measure is not ideal, as face recognition depends on configural information rather than on recognition of individual features (e.g., Diamond and Carey, 1986). That is, while people may only be able to verbalize individual facial features (e.g., she has big eyes and she has freckles on her nose), face recognition depends upon hard-to-verbalize configural information about the relationship of features to one another (e.g., the relationship between the eyes and the nose).

Support for the recoding hypothesis comes from a meta-analysis of the literature about the type of instructions given to witnesses. Meissner and Brigham (2001) coded each study's instructions to participants as either standard or elaborative. Instructions were considered elaborative if "the authors explicitly encouraged their participants to go beyond their normal criterion of free recall and to provide more elaborative descriptions" (Meissner and Brigham, 2001: 607). Presumably, elaborative descriptions led to less accurate recodings; consistent with this, elaborative descriptions were more likely to lead to verbal overshadowing than were descriptions resulting from standard free recall instructions (Meissner and Brigham, 2001). One study published since the meta-analysis deserves mention here. MacLin (2002) compared the effects of several different types of instructions on the verbal overshadowing effect. When participants were told to describe facial features, the standard effect occurred: On a later test, participants were less likely to identify the target than were control participants who did not describe the target. However, when participants were told to write a description comparing the target to a famous person such as Julia Roberts (the exemplar condition), verbal overshadowing was reduced. The effect disappeared in a prototype condition in which participants described "what type of person you think he most looks like" (MacLin, 2002: 932) in terms of occupation and personality. Thus, verbal overshadowing was most likely in the condition in which recoding emphasized facial features rather than more holistic information about the target face.

A second explanation of verbal overshadowing also hinges on the fact that descriptions often emphasize individual facial features rather than configural information. However, rather than proposing that a feature-based description interferes with retrieval of the original memory, the argument is that verbalization induces a processing shift at test (Dodson et al., 1997; Schooler, 2002). That is, because descriptions of faces emphasize individual features (as it is hard to verbalize relations between features), the participant carries over this type of processing to test. This is considered a processing shift, as face identification is normally based on configural information rather than features; carrying over a featural orientation would constitute inappropriate processing. One interesting finding is shown in **Figure 2**. Dodson and colleagues had participants view a target face and then do one of three tasks: Describe the target face, describe a parent's face, or list U.S. states and capitals (a control condition). As shown in the figure, describing any face (e.g., a relative's) reduced participants' ability to identify the target (Dodson et al., 1997). This is hard to reconcile with the idea that a recoded representation (of the target) is interfering with access to the original memory. Rather, it suggests that anything that emphasizes featural processing will encourage that same type of processing at test.

Similar conclusions were reached by Finger (2002), who added a second factor to the typical verbal overshadowing experiment. She crossed description (describe vs. control) with a post-description task (verbal vs. mazes). When solving mazes followed the face description, verbal overshadowing disappeared. In a second experiment, Finger replicated the effect with a second nonverbal task, namely listening to music. Engaging in holistic processing can change the processing set from one that emphasizes individual features to one that does not, with consequences for face identification.

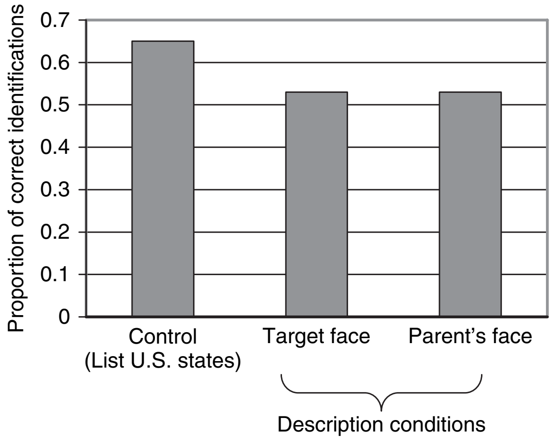


**Figure 2** Recognition of target face after describing target face, parent's face, or listing U.S. states and capitals. Data from Dodson CS, Johnson MK, and Schooler JW (1997) The verbal overshadowing effect: Why descriptions impair face recognition. *Mem. Cogn.* 25: 129–139, Experiment 2.

Recent research suggests a number of relatively simple solutions to minimize the effects of verbal overshadowing of faces, such as inserting a delay between description and test (Finger and Pezdek, 1999) and preceding the test with a task that encourages configural processing (Finger, 2002). It remains to be tested whether these solutions are equally effective at reducing verbal overshadowing of other types of perceptual stimuli such as voices, wines, and maps.

## 2.14.4 Misattributions of Familiarity

Thus far, we have discussed misremembering laboratory events – be it misremembering a word that was never presented in a study list (in the DRM paradigm), incorrectly recalling a detail of a slide show (in the misinformation paradigm), or misidentifying a person from a video (in verbal overshadowing experiments). In contrast, in the next paradigm we will review, the memory error involves misattributing something learned in the laboratory to pre-experimental experience. More specifically, the paradigm is a recipe for fame; Larry Jacoby used straightforward experimental manipulations to make ordinary names appear famous.

The names Brad Pitt, Mark McGwire, and Sandra Day O'Connor are likely recognizable to you. In addition to agreeing that you have heard of these people before, you can probably justify your response by telling us Brad Pitt is an actor, Mark McGwire is an athlete, and Sandra Day O'Connor is a retired Supreme Court justice. You can also tell me whether or not other names are the names of famous people, even if you cannot say exactly why each person is famous. For example, try to identify the three famous people in the following list of six names: Zoe Flores, Minnie Pearl, Jessica Lynch, Joanna Emmons, Summer Foster, Hattie Caraway. Hopefully, at least one or two of the names will seem familiar to you, even if you do not know what accomplishments to associate with each name. Quite simply, the false fame paradigm increases the familiarity of nonfamous names (like Zoe Flores, Joanna Emmons, and Summer Foster) and places the respondent in a situation where familiarity is interpreted as fame.

In the typical paradigm, participants read a list of names explicitly labeled as nonfamous. In a second phase, participants judge the fame of each of a series of names; the test list includes moderately famous names like Minnie Pearl, new nonfamous names, and old nonfamous names that were read in the first part of the experiment. Critically, half of the participants are required to do a secondary task (e.g., monitoring an auditory stream of numbers for a series of three odd numbers in a row) at the same time as the fame judgment task. In the full-attention (control) condition, old nonfamous names are less likely to be judged famous than are new nonfamous names; in this condition, if participants can remember a name is old, then they can assume it is not famous. In contrast, in the divided-attention condition, participants are more likely to call old nonfamous names famous ($M = 0.28$) than new nonfamous names ($M = 0.14$) (Jacoby et al., 1989b). The logic is that under divided attention, participants are forced to base their judgments on the familiarity of a name, and that the cognitive load interferes with their ability to recollect whether names were presented in the first part of the experiment.

The false fame effect requires conditions that force participants to rely on familiarity rather than recollecting information about the names. For example, the false fame effect also occurs when attention is divided during encoding, as presumably that prevents encoding of item-specific information (Jacoby et al., 1989a). Similarly, under conditions of full attention, the illusion requires a delay between study of the nonfamous names and the fame judgments. Consistent with the idea that the false fame effect is familiarity driven, the effect is stronger in populations that are more likely to rely on familiarity, such as older adults (Bartlett et al., 1991; Multhaup, 1995).

This illusion is related to a more general framework on how people interpret feelings of familiarity. Vague feelings of familiarity are not specific to names; there are many situations in which familiarity is experienced and the perceiver must attribute that familiarity to something. In an impressive series of studies, Jacoby has shown that how that familiarity is interpreted depends on the experimental context. Familiarity can be interpreted as fame, but it can also lead to illusions of duration and noise level, for example. At test, previously studied words are judged to be presented longer than are new words (Witherspoon and Allan, 1985) and background noise is judged to be quieter for old sentences than for new sentences (Jacoby et al., 1988). The familiarity of the items causes them to be processed fluently, and in the context of perceptual judgments, this fluent processing is interpreted as perceptual conditions that aid identification of the items.

Familiarity may also play a role in the déjà vu experience (Brown, 2003, 2004). In the prior examples in this section, familiarity was successfully attributed to a source, albeit incorrectly: Familiarity was misinterpreted as fame and longer presentation durations, among other things. In contrast, déjà vu occurs when something feels familiar but the familiarity cannot be attributed to any prior experience. It is this unexplained familiarity with a situation that yields the puzzling déjà vu reaction. One hypothesis is that the individual previously experienced all or part of the present situation or setting, but cannot explicitly remember it. Thus implicit memory yields a familiarity response that is puzzling given the lack of episodic memory. Because déjà vu is a relatively infrequent phenomenon (Brown, 2003, 2004), it is difficult to capture in the laboratory. Some support for the implicit memory hypothesis, however, has been found in a laboratory paradigm (Brown and Marsh, in press). In this study, students from Duke University and Southern Methodist University viewed photos of the away campus in an initial exposure phase (none of these students reported having visited the other campus in real life). During the initial session, participants made a simple perceptual judgment about each of 216 photos, which included the target away-campus photos as well as many filler photos. One week later, participants made judgments about whether or not they had visited each of a series of test photos. Critically, in addition to familiar places from their home campus, participants judged photos from the prior session. Prior exposure to away-campus scenes boosted participants' beliefs that they had visited the places in real life. Intriguingly, almost half of participants reported experiencing something like déjà vu in the study. In this case, familiarity with a scene influenced belief that the place had been visited in real life, and sometimes this familiarity was puzzling enough to be labeled as déjà vu (*See* Chapter 2.21).

In this section, we described how familiarity could be interpreted as fame as well as perceptual attributes such as the volume of noise. In the next section, we will consider whether familiarity with an event can increase people's beliefs that an event happened in their pasts.

## 2.14.5 Imagination Inflation

The relationship between imagery and perception has a long intellectual history, reaching back to philosophers such as Hume and Mills. In the 1970s, the key question involved the nature of the representation underlying images. In this context, Johnson and colleagues asked how we separate memories for images from memories based on perception. More generally, reality monitoring involves deciding whether a memory originated from an internal or external source, with internal sources being cognitive processes such as imagery, thought, and dreams. Johnson argued that internally generated and externally presented memories tend to differ in prototypical ways, and that these differences in qualitative characteristics were the basis for attributing memories to thought versus perception (e.g., Johnson and Raye, 1981). Compared to memories based on perception, memories of images were postulated to be less vivid and to be associated with the cognitive operations involved in their generation. Reality monitoring errors occur when memories contain characteristics atypical of their class. For example, easily generated images are more likely to be misattributed to perception than are difficult-to-imagine objects. Easily generated images are likely atypically vivid; in addition, their easy generation means they are not associated with a record of cognitive operations (Finke et al., 1988).

Misattributions of imagined events to perception have been documented with many different kinds of stimuli, including imagined voices (Johnson et al., 1988), imagined rotations of alphanumeric characters (Kahan and Johnson, 1990), and imagined pictures (Johnson et al., 1982). But can imagery cause confusions beyond these types of simple laboratory stimuli? That is, if you imagine an event, will you later come to believe that it really happened?

Garry and colleagues (1996) created a three-stage procedure to answer this question. In the first part of the experiment, participants rated the likelihood that they had experienced each of a series of life experiences (the Life Events Inventory; LEI), including winning a stuffed animal at a fair and breaking a window with one's hand. Two weeks after reading descriptions of the target events, participants imagined both the setting and the action of events in response to specific prompts. For example, in the broken window event, participants spent 20–60 s imagining the following setting: "It is after school and you are playing in the house. You hear a strange noise outside, so you run to the window to see what made the noise. As you are running, your feet catch on something and you trip and fall" (Garry et al., 1996: 210). After the imagination phase was finished, the experimenter pretended to have lost the original LEI and asked participants to fill out the questionnaire for a second time.

There were eight critical events judged unlikely to have occurred for a majority of the participants, and each participant imagined four of those during phase 2. Of interest was whether participants were more likely to change their beliefs about events they had imagined in phase 2, as compared to the control events not imagined. Garry et al. examined the percentage of critical items that were rated as more likely to have happened at time 2 (after the imagery phase) than at time 1. Increases in likelihood ratings were more common for imagined events than for control events. For example, consider the effect of imagining on people's beliefs that as a child they broke a window with their bare hand. The likelihood ratings increased from time 1 to time 2 for 24% of participants in the imagery condition, as compared to only 12% of control participants.

It is possible, of course, that participants had actually experienced these unusual events and that imagining them helped to cue the previously forgotten memories. One solution to this criticism is to control the original events in the laboratory, to allow certainty about what actually occurred. Because this is not possible with childhood memories, Goff and Roediger (1998) brought the encoding phase into the laboratory. The experiment had three sessions; during the first session, participants enacted, heard, or imagined simple events. For example, when the experimenter read aloud the sentence 'bounce the ball,' one participant would simply listen; another would imagine bouncing the ball, and a third would actually bounce the ball. Twenty-four hours later, participants returned for a second session in which half of participants imagined events and half did math problems. In the imagery condition, participants were guided to imagine each event zero, one, three, or five times; the events included ones from the first session as well as completely new events. Participants in this condition rated the vividness of each image. Finally, 2 weeks after the initial session, participants were given recognition and source monitoring tests. Participants were explicitly told that their memory was being tested for the first day only. They were first asked if they remembered hearing certain events. If they answered no, they gave a confidence rating in their answer. If they answered yes, they specified the format of the remembered event (heard and enacted, heard and imagined, or heard only) and rated their confidence in that judgment. Of interest was whether imagining new events in session 2 would increase beliefs that the events had been performed in session 1. Replicating findings from studies using LEI measures, Goff and Roediger found that events that were only imagined during the second session were later misremembered as having been performed during the first session. Imagining a bouncing ball in the second session increased participants' beliefs that they had actually bounced a ball in the first session. Furthermore, as the number of imaginings in session 2 increased, participants were more likely to incorrectly label a never-performed action as having been performed in the first session, as shown in **Figure 3**.

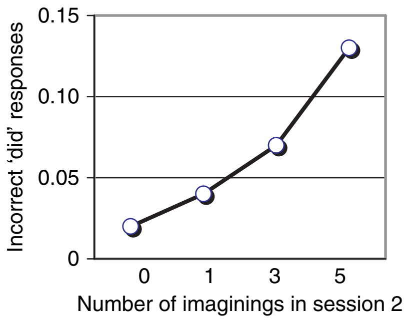


**Figure 3** False 'did' judgments for never-performed actions as a function of number of imaginings in session 2. Data from Goff LM and Roediger HL III (1998) Imagination inflation for action events: Repeated imaginings lead to illusory recollections. *Mem. Cogn.* 26: 20–33.

The finding of imagination inflation for laboratory events supports the idea that imagination can yield false memories and that the effects observed with the LEI cannot be attributed solely to recovery of previously forgotten events. Why do these effects occur? In their original demonstration of imagination inflation, Garry and colleagues favored a reality monitoring explanation, whereby an imagined memory was misattributed to perception. Specifically, Garry et al. argued that imagination increased the perceptual information associated with the events, thus increasing the similarity of these imagined memories to performed events. This account predicts that imagination inflation should be greater when images are detailed, as they will be more readily confused with perception. Consistent with this hypothesis, Thomas and colleagues (2003) found that elaborative imagery instructions increased the imagination inflation effect, as compared to standard imagery instructions. Like Goff and Roediger, Thomas' participants completed an initial encoding phase and returned a day later for the imagination phase. Instructions in the simple imagery condition paralleled Goff and Roediger; for example, participants were asked to 'imagine getting up and opening the door.' Participants in the elaborative imagery condition were to imagine two additional statements, which included two sensory modalities; for example, 'Imagine getting up and opening the door. Imagine how the door handle feels in your hand. Imagine how the door sounds as you open it.' If the event was not imagined in the middle session, participants were very good at identifying new events. However, imagining events in the middle session led to imagination inflation, and this effect was bigger (12%) following elaborative imagery than simple imagery (7%).

To recap, imagining events may increase their vividness, a key characteristic of perceived memories. This is not the only explanation for the imagination inflation effect, however. Imagining events may also increase their familiarity, which can also lead to memory misattributions (as described in the previous section of this chapter). The imagination scripts used to guide the imagery also usually contain a lot of suggestive information over and above the vivid images generated by the participant. In short, does imagination underlie the effect, or is the effect at least partly driven by familiarity (as discussed in the section on false fame), as opposed to imagination?

Several data points suggest that imagining vivid details is not necessary to increase beliefs that events occurred in childhood. For example, similar effects are observed when participants paraphrase the script normally used to guide imagery (Sharman et al., 2004). The data also look similar when participants explain how the events might have happened in one's childhood (Sharman et al., 2005). Of course, in both of these cases, it is possible that participants might spontaneously generate images even though they were not explicitly directed to do so. However, Bernstein and colleagues observed inflation in a study in which spontaneous generation of images was quite unlikely. Their study extended the revelation effect to autobiographical memory (Bernstein et al., 2002). The revelation effect is the finding that requiring participants to unscramble a stimulus (to reveal it) increases the likelihood that it will be judged 'old' (Westerman and Greene, 1996). Bernstein et al. found that participants were more likely to believe childhood events had in fact occurred if they had to unscramble the events before judging them (e.g., 'broke a dwniwo playing ball'). Unscrambling presumably does not encourage imagery, and thus it suggests that LEI ratings can be based on factors other than image vividness, such as familiarity.

It should be clear that the just-described results do not negate the role of imagination in false memory creation. Finding that explaining, paraphrasing, and unscrambling events can all inflate confidence in remembered events does not preclude imagination also playing a role. Rather, such results emphasize the importance of isolating the contribution of imagination, as imagination is often combined with other factors that yield false memories.

### 2.14.6 Implanted Autobiographical Memories

It is possible to make a person remember a word that was never presented, to misjudge the fame of a name, or to misremember a detail from a witnessed event. But do people ever falsely remember entire events? The answer is yes. Consider the case of Shauna Fletcher, who came to believe her horrible memories of childhood sexual abuse were false memories (Pendergrast, 1996). How could this happen? Shauna traced her memories to several different sources, blaming her therapist for suggesting that the events occurred, and books and movies for providing the images she remembered. Shauna's experiences parallel the findings from laboratory studies: Implanting memories is possible, but not simple. A single misleading statement does not yield the kind of false memories experienced by Shauna. Correspondingly, the laboratory procedures for implanting entire memories tend to be much more complicated than those described earlier in the chapter, oftentimes combining multiple suggestive techniques.

Loftus and Pickrell (1995) demonstrated that false autobiographical memories can be implanted using laboratory techniques. The critical false memory involved being lost in a shopping mall as a child. To camouflage the purpose of the experiment, participants were also interviewed about childhood events that had actually occurred; a close relative of the participant provided the true memories. The relative also provided plausible details to aid in constructing the false memory (e.g., stores the family shopped, other family members likely to have been present, etc.) and verified that the participant had not been lost in a shopping mall around the critical time period (age 5).

Participants reviewed four events: three that were true and the critical false event. Each event was described in a booklet, and participants were instructed to remember the events and to write about the specific details of each. If participants did not remember the event, they were to indicate that on the form. Approximately 1–2 weeks later, participants were interviewed about the events. In addition to recalling details of the events, participants rated each memory for clarity (1 = not clear; 10 = extremely clear) and confidence that additional details could be remembered later (1 = not confident; 5 = extremely confident). A second interview, conducted 1–2 weeks later, was similar to the first interview.

Did participants come to remember being lost in the shopping mall at age 5? Critically, seven out of 24 participants claimed to remember the false memory (fully or partially) while writing about it in the initial booklet. Although their descriptions of the false events were shorter than those of true memories, the clarity ratings given to these false memories increased across interviews. At the end of the experiment, five participants were unable to pick out the false event and instead guessed that one of the true events had never happened.

The reader may be wondering why we consider the Loftus and Pickrell (1995) study to be an example of successful memory implantation. After all, most participants never believed the lost-in-the-mall memory and were able to identify it as the false event. What is crucial is that the implantation rate was above zero. That is, to argue that implanting false memories is possible, one only needs to show one successful implantation.

False memories are not limited to erroneous memories of being lost in the mall as a child. Experimenters have been successful at implanting many different types of events in participants. Participants have come to falsely remember participating in a religious ceremony (Pezdek et al., 1997), riding in a hot air balloon (Wade et al., 2002), putting the gooey toy Slime in an elementary school teacher's desk (Lindsay et al., 2004), and being admitted to the hospital (Hyman et al., 1995). Different approaches have been taken to ensure a false memory was in fact implanted, as opposed to a true memory being recovered. One is to confirm events with parents, as Loftus and Pickrell (1995) did. Another is to choose events that are very implausible, or even impossible. Braun and colleagues (2002) used the latter approach, implanting false memories for meeting a Warner Brothers character, Bugs Bunny, at Disneyland.

The procedures for implanting false memories are often elaborate, far beyond the simple suggestions typical of eyewitness misinformation studies. Successful studies typically follow three rules of thumb (Mazzoni et al., 2001; Lindsay et al., 2004). First, the target event must be deemed plausible. For example, it is easier to implant a false memory for being lost in the mall than it is to implant a false memory of an enema (Pezdek et al., 1997; see also Hart and Schooler, 2006). Second, the target event must be elaborated upon. For example, suggestibility was greater for participants who were required to imagine and describe the target events, probably because the guided imagery task led to more detailed memories (Hyman and Pentland, 1996). Third, the products of this elaboration must be attributed to memory, as opposed to other sources.

Although this framework is generally useful for thinking about memory implantation, one difficulty is that many manipulations likely affect more than one process. Consider, for example, Pezdek and colleagues' difficulty in implanting a false memory involving a Catholic ceremony (the Eucharist) in Jewish participants. Were the Jewish participants able to reject the event because it was implausible to them or because they were not familiar enough with the event to elaborate upon the suggestion? Similarly, consider what happens when a participant sees a doctored photograph depicting her engaged in the target false event. In this type of study, after a relative verifies that the participant has never ridden in a hot air balloon, Photoshop is used to insert a real childhood photo into a photograph depicting a hot air balloon ride (Wade et al., 2002). Such a procedure yields false memories in about half of participants (a high rate) – but is unclear at a cognitive level how the photograph has its effect on memory. The very existence of a photograph of the event increases the plausibility of the event, as well as providing vivid details about the supposed event.

The aforementioned examples illustrate the challenge of doing research in this area, namely the difficulty of linking manipulations to specific cognitive processes. We do not, however, intend to be pessimistic. The demonstrations of memory implantation were critical first steps, and they are being followed by systematic manipulations aimed at better elucidating the underlying cognitive processes. Rather than trying to equate different events with different levels of an independent variable, one approach is to try to implant the same event while experimentally manipulating a variable that affects only one possible factor, such as plausibility. Mazzoni and colleagues took this approach when examining memories for demonic possession (Mazzoni et al., 2001). Keeping the target event constant, they showed that reading articles about possession dramatically increased later beliefs that one had witnessed a demonic possession (as compared to the control group).

One of the major puzzles in this research area is why vivid false memories can be successfully implanted in some participants but not others. For example, across eight well-cited studies, Lindsay et al. (2004) observed that the implantation rate ranged from 0% to 56% of participants! We know of no study in which the false memory was successfully implanted into 100% of participants. Thus we predict one fruitful avenue for future research will be investigating individual differences in suggestibility. In the best study to date, Hyman and Billings (1998) looked for relationships between rates of false memory implantation and scores on four cognitive/personality scales. Two interesting results emerged. First, false memory scores were higher for participants who scored higher on the Creative Imagination Scale (CIS), a scale that measures imagery ability as well as suggestibility. In other words, participants who were better able to elaborate upon the suggestion were more likely to come to remember the false event. Second, false memory scores were higher for participants who scored higher on the Dissociative Experiences Scale (DES), a scale that measures both normal experiences such as distraction as well as less normal experiences such as hearing voices. Scoring higher on the DES may be related to difficulties with source monitoring.

In short, implanting detailed false memories is a complex process. It combines many of the techniques described earlier in the chapter in the context of other false memory paradigms, including imagery instructions, misleading suggestions, and a test situation that does not encourage participants to evaluate the source(s) of their memories. In this context, we turn to a discussion of how the various memory errors relate to one another.

## 2.14.7 Connections Across False Memory Paradigms

We have described six different paradigms that yield memory errors: The DRM paradigm, the eyewitness misinformation paradigm, verbal overshadowing studies, misattributions of familiarity, imagination inflation, and implanted autobiographical memories. What is the relationship between these very different paradigms?

We linked each memory error to possible mechanisms: Spreading activation (and monitoring of that activation) in the DRM paradigm, interference and failure to monitor source in the misinformation paradigm, an inappropriate shift in processing at test in the verbal overshadowing paradigm, a misattribution of familiarity in the false fame effect, increased familiarity and vividness (and possibly reality monitoring failures) in imagination inflation, and elaboration and source misattribution in the implanted memory studies. Sometimes, the same mechanism is implicated across illusions; for example, source monitoring failures are implicated in the misinformation effect and in implanting false autobiographical memories. Imagination inflation likely involves reality-monitoring errors, a specific type of source error. Misattributions of activation (in the DRM paradigm) and familiarity (as observed in the false fame paradigm) can also be interpreted as source errors. In other cases, the mechanisms appear qualitatively different, as in the case of the transfer inappropriate processing shift in verbal overshadowing studies. Of course, one issue is that likely more than one mechanism is involved in each illusion (and the convergence of mechanisms is probably why the errors are so robust). For example, imagination inflation likely depends on both vivid encoding (which may also increase familiarity) and some kind of monitoring failure at test. One other point worth noting is that even if the same mechanism is implicated in two different illusions, the instantiations of that mechanism may be quite different. For example, even though source errors are implicated in both the DRM illusion and the misinformation effect, giving participants a source test has very different effects in the two cases. As already mentioned, a source test can reduce susceptibility to post-event information (e.g., Lindsay and Johnson, 1989; Zaragoza and Lane, 1994). However, source tests yield more puzzling results when used in the DRM paradigm; depending on the features of the source test, the rate of false memories may be higher (Hicks and Marsh, 2001), lower (Multhaup and Conner, 2002), or similar (Hicks and Marsh, 1999) to that observed on item memory tests.

More generally, comparing the effects of standard manipulations on the different measures of suggestibility is a useful way of examining similarities and differences across false memory paradigms. For example, many researchers are interested in differences in suggestibility between children and college students. This comparison has been made in at least three of the six paradigms we described – DRM, eyewitness misinformation, and implanted memories – and the conclusion about age is not the same across paradigms. For example, younger children are normally more suggestible in eyewitness misinformation paradigms than are older children (Bruck and Ceci, 1999), but older children are more suggestible than younger children in the DRM paradigm (e.g., Brainerd and Reyna, 2007). That is, even though there are clear age differences in source monitoring abilities (e.g., Lindsay et al., 1991), with older children doing better than younger, older children are more suggestible in the DRM paradigm. Why is this, given that we already alluded to the role of source monitoring in the DRM paradigm? The paradox can be resolved by attributing the key age difference to encoding, rather than to retrieval-based processes such as source monitoring. Specifically, because younger children have difficulty noting semantic relations between items (Brainerd and Reyna, 2007), they may be less likely to encode the critical lure. In the terms of activation-monitoring theory, activation will be less likely to spread to the critical lure from related studied items; in the terms of fuzzy trace theory, younger children will be less likely to extract the gist of the list. By either account, the result is the same: It does not matter if younger children are poor at source monitoring if there is no trace for them to attribute to a source! Again, this example highlights the inadequacy of simply attributing DRM and eyewitness errors to difficulties with source; the full picture is more complicated.

There are at least two other approaches for connecting false memory paradigms. One is to test the same participants in multiple paradigms, and another is to link false memory in different paradigms to the same standardized measures of individual differences. The logic is that if comparable mechanisms underlie the errors, then the same individuals (or the same types of people) should perform similarly across paradigms. For example, Clancy and colleagues (2002) examined suggestibility in the DRM paradigm in control participants and in people who believed aliens had abducted them. Memories of alien abduction are of interest since the scientific community views alien abductions as impossible occurrences, leading these memories to be classified as false memories (although not implanted in the laboratory, of course). Interestingly, false recognition of nonpresented words was higher for people with alien abduction memories ($M = 0.67$) than for control participants ($M = 0.42$). In this same study, correlations between false memory and scores on individual difference scales were also observed. The rate of false memories was greater for individuals who scored highly on scales measuring absorption and dissociative experiences (DES) and reported more symptoms of post-traumatic stress disorder. The reader will recall that the DES is a scale that measures both normal experiences such as distraction as well as less normal experiences such as hearing voices, and that higher scores on the DES may be related to difficulties with source monitoring. Higher DES scores predicted implantation of a false childhood memory for spilling punch on the mother of the bride, although absorption did not (Hyman and Billings, 1998). Scores on the DES have also been related to imagination inflation (Paddock et al., 1999), and pathological scores on this scale have been linked to suggestibility in the eyewitness misinformation paradigm (Eisen et al., 2001). However, DES scores are not related to susceptibility to the false fame illusion (Peters et al., 2007). Understanding such individual differences will likely be an important part of future research on memory errors and suggestibility.

We end with a note on another approach we believe will help elucidate the relationships between different false memory paradigms: neuroimaging. Consider a study by Cabeza and colleagues (2001), in which participants watched two very different sources (a Caucasian male and an Asian female) read DRM-like lists, followed by a recognition memory test. At test, studied words and critical lures yielded similar activation in anterior medial temporal lobe (MTL) areas, but activation in posterior MTL differentiated true and false memories. Cabeza et al. associated anterior MTL with retrieval of semantic information and posterior MTL with perceptual information. What would the pattern be like for familiarity-driven illusions, such as false fame? To the extent that the same mechanisms underlie different memory errors, similar patterns of activation should occur.

## 2.14.8 Conclusions

In this chapter, we reviewed just six of the many published paradigms for creating false memories. Together, the data highlight the constructive nature of memory, as proposed by Bartlett (1932). We have also tried to stress that not all memory errors are equal. Not surprisingly, given the complexity of memory, there are many different ways that error can enter the system, from encoding to retrieval.

While we have focused on errors, we would be remiss not to point out that reconstructive memory is often very useful. For example, familiarity often is an excellent cue that something has been experienced before, and it is only in certain situations that this heuristic leads to error. More generally, errors are often the by-product of processes that support veridical memory. Memory errors are more than intriguing illusions. A thorough understanding of memory's errors will provide insight into the processes that normally aid memory.

## References


Bahrick HP, Bahrick PO, and Wittlinger RP (1975) Fifty years of memory for names and faces: A cross-sectional approach. *J. Exp. Psychol. Gen.* 104: 54–75.

Balota DA, Cortese MJ, Duchek JM, et al. (1999) Veridical and false memories in healthy older adults and in dementia of the Alzheimer's type. *Cogn. Neuropsychol.* 6: 361–384.

Bartlett FC (1932) *Remembering: A Study in Experimental and Social Psychology*. Cambridge: Cambridge University Press.

Bartlett JC, Strater L, and Fulton A (1991) False recency and false fame of faces in young adulthood and old age. *Mem. Cogn.* 19: 177–188.

Benjamin AS (2001) On the dual effects of repetition on false recognition. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 941–947.

Berntsen D and Thomsen DK (2005) Personal memories for remote historical events: Accuracy and clarity of flashbulb memories related to World War II. *J. Exp. Psychol. Gen.* 134: 242–257.

Bernstein DM, Whittlesea BWA, and Loftus EF (2002) Increasing confidence in remote autobiographical memory and general knowledge: Extensions of the revelation effect. *Mem. Cogn.* 30: 432–438.

Brainerd CJ and Reyna VF (2002) Fuzzy-trace theory and false memory. *Curr. Dir. Psychol. Sci.* 11: 164–169.

Brainerd CJ and Reyna VF (2007) Explaining developmental reversals in false memory. *Psychol. Sci.* 18: 442–448.

Braun KA, Ellis R, and Loftus EF (2002) Make my memory: How advertising can change our memories of the past. *Psychol. Mark.* 19: 1–23.

Brown AS (2003) A review of the déjà vu experience. *Psychol. Bull.* 129: 394–413.

Brown AS (2004) The déjà vu illusion. *Curr. Dir. Psychol. Sci.* 13: 256–259.

Brown AS and Marsh EJ (in press) Evoking false beliefs about autobiographical experience. *Psychon. Bull. Rev.*

Brown NR, Buchanan L, and Cabeza R (2000) Estimating the frequency of nonevents: The role of recollection failure in false recognition. *Psychon. Bull. Rev.* 7: 684–691.

Bruck M and Ceci SJ (1999) The suggestibility of children's memory. *Annu. Rev. Psychol.* 50: 419–439.

Butler KM, McDaniel MA, Dornburg CC, Price AL, and Roediger HL III (2004) Age differences in veridical and false recall are not inevitable: The role of frontal lobe function. *Psychon. Bull. Rev.* 11: 921–925.

Cabeza R, Rao SM, Wagner AD, Mayer AR, and Schacter DL (2001) Can medial temporal lobe regions distinguish true from false? An event-related functional MRI study of veridical and illusory memory. *Proc. Natl. Acad. Sci. USA* 98: 4805–4810.

Carmichael L, Hogan HP, and Walter AA (1932) An experimental study of the effect of language on the reproduction of visually perceived forms. *J. Exp. Psychol.* 15: 73–86.

Choi H and Smith SM (2005) Incubation and the resolution of tip-of-the-tongue states. *J. Gen. Psychol.* 132: 365–376.

Christianson S-A (1992) Emotional stress and eyewitness memory: A critical review. *Psychol. Bull.* 112: 284–309.

Clancy SA (2005) *Abducted: How People Come to Believe They Were Kidnapped by Aliens*. Cambridge, MA: Harvard University Press.

Clancy SA, Schacter DL, Lenzenweger MF, and Pittman RK (2002) Memory distortion in people reporting abduction by aliens. *J. Abnorm. Psychol.* 111: 455–461.

Collins AM and Loftus EF (1975) A spreading-activation theory of semantic processing. *Psychol. Rev.* 82: 407–428.

Deese J (1959) On the prediction of occurrence of particular verbal intrusions in immediate recall. *J. Exp. Psychol.* 58: 17–22.

Diamond R and Carey S (1986) Why faces are and are not special: An effect of expertise. *J. Exp. Psychol. Gen.* 115: 107–117.

Dodson CS and Schacter DL (2001) If I said it I would have remembered it: Reducing false memories with a distinctiveness heuristic. *Psychon. Bull. Rev.* 8: 155–161.

Dodson CS, Johnson MK, and Schooler JW (1997) The verbal overshadowing effect: Why descriptions impair face recognition. *Mem. Cogn.* 25: 129–139.

Dooling DJ and Christiaansen RE (1977) Episodic and semantic aspects of memory for prose. *J. Exp. Psychol. Hum. Learn. Mem.* 3: 428–436.

Douglass AB and Steblay N (2006) Memory distortion in eyewitnesses: A meta-analysis of the post-identification feedback effect. *Appl. Cogn. Psychol.* 20: 859–869.

Eisen ML, Morgan DY, and Mickes L (2001) Individual differences in eyewitness memory and suggestibility: Examining relations between acquiescence, dissociation and resistance to misleading information. *Pers. Ind. Diff.* 33: 553–571.

Finger K (2002) Mazes and music: Using perceptual processing to release verbal overshadowing. *Appl. Cogn. Psychol.* 16: 887–896.

Finger K and Pezdek K (1999) The effect of the cognitive interview on face identification accuracy: Release from verbal overshadowing. *J. Appl. Psychol.* 84: 340–348.

Finke RA, Johnson MK, and Shyi GC (1988) Memory confusions for real and imagined completions of symmetrical visual patterns. *Mem. Cogn.* 16: 133–137.

Fiore SM and Schooler JW (2002) How did you get here from there? Verbal overshadowing of spatial mental models. *Appl. Cogn. Psychol.* 16: 897–910.

Gabbert F, Memon A, and Allan K (2004) Say it to my face: Examining the effects of socially encountered misinformation. *Legal Criminol. Psychol.* 9: 215–227.

Gallo DA and Roediger HL III (2002) Variability among word lists in eliciting memory illusions: Evidence for associative activation and monitoring. *J. Mem. Lang.* 47: 496–497.

Garry M, Manning CG, Loftus EF, and Sherman SJ (1996) Imagination inflation: Imagining a childhood event inflates confidence that it occurred. *Psychon. Bull. Rev.* 3: 208–214.

Gentner D and Loftus EF (1979) Integration of verbal and visual information as evidenced by distortions in picture memory. *Am. J. Psychol.* 92: 363–375.

Goff LM and Roediger HL III (1998) Imagination inflation for action events: Repeated imaginings lead to illusory recollections. *Mem. Cogn.* 26: 20–33.

Greene E, Flynn MS, and Loftus EF (1982) Inducing resistance to misleading information. *J. Verb. Learn. Verb. Behav.* 21: 207–219.

Hart RE and Schooler JW (2006) Increasing belief in the experience of an invasive procedure that never happened: The role of plausibility and schematicity. *Appl. Cogn. Psychol.* 20: 661–669.

Hashtroudi S, Johnson MK, and Chrosniak LD (1989) Aging and source monitoring. *Psychol. Aging* 4: 106–112.

Hicks JL and Marsh RL (1999) Attempts to reduce the incidence of false recall with source monitoring. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 1195–1209.

Hicks JL and Marsh RL (2001) False recognition occurs more frequently during source identification than during old-new recognition. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 375–383.

Hyman IE Jr. and Billings FJ (1998) Individual differences and the creation of false childhood memories. *Memory* 6: 1–20.

Hyman IE Jr. and Pentland J (1996) The role of mental imagery in the creation of false childhood memories. *J. Mem. Lang.* 35: 101–117.

Hyman IE Jr., Husband TH, and Billings FJ (1995) False memories of childhood experiences. *Appl. Cogn. Psychol.* 9: 181–197.
Israel L and Schacter DL (1997) Pictorial encoding reduces false recognition of semantic associates. *Psychon. Bull. Rev.* 4: 577–581.
Jacoby LL, Allan LG, Collins AM, and Larwill LK (1988) Memory influences subjective experience: Noise judgments. *J. Exp. Psychol. Learn. Mem. Cogn.* 14: 240–247.
Jacoby LL, Kelley CM, Brown J, and Jasechko J (1989a) Becoming famous overnight: Limits on the ability to avoid unconscious influences of the past. *J. Pers. Soc. Psychol.* 56(3): 326–338.
Jacoby LL, Woloshyn V, and Kelley CM (1989b) Becoming famous without being recognized: Unconscious influences of memory produced by dividing attention. *J. Exp. Psychol. Gen.* 118: 115–125.
Johnson MK and Raye CL (1981) Reality monitoring. *Psychol. Rev.* 88: 67–85.
Johnson MK, Raye CL, Foley MA, and Kim JK (1982) Pictures and images: Spatial and temporal information compared. *Bull. Psychon. Soc.* 19: 23–26.
Johnson MK, Foley MA, and Leach K (1988) The consequences for memory of imagining in another person's voice. *Mem. Cogn.* 16: 337–342.
Johnson MK, Hashtroudi S, and Lindsay DS (1993) Source monitoring. *Psychol. Bull.* 114: 3–28.
Kahan TL and Johnson MK (1990) Memory for seen and imagined rotations of alphanumeric characters. *J. Ment. Imagery* 14: 119–129.
Lane SM (2006) Dividing attention during a witnessed event increases eyewitness suggestibility. *Appl. Cogn. Psychol.* 20: 199–212.
Lindsay DS and Johnson MK (1989) The eyewitness suggestibility effect and memory for source. *Mem. Cogn.* 17: 349–358.
Lindsay DS, Johnson MK, and Kwon P (1991) Developmental changes in memory source monitoring. *J. Exp. Child Psychol.* 52: 297–318.
Lindsay DS, Hagen L, Read JD, Wade KA, and Garry M (2004) True photographs and false memories. *Psychol. Sci.* 15: 149–154.
Loftus EF (1979) Reactions to blatantly contradictory information. *Mem. Cogn.* 7: 368–374.
Loftus EF (1992) When a lie becomes memory's truth: Memory distortion after exposure to misinformation. *Curr. Dir. Psychol. Sci.* 1: 121–123.
Loftus EF and Palmer JC (1974) Reconstruction of automobile destruction: An example of the interaction between language and memory. *J. Verb. Learn. Verb. Behav.* 13: 585–589.
Loftus EF and Pickrell JE (1995) The formation of false memories. *Psychiatr. Ann.* 25: 720–725.
Loftus EF, Miller DG, and Burns HJ (1978) Semantic integration of verbal information into a visual memory. *J. Exp. Psychol. Hum. Learn. Mem.* 4: 19–31.
Loftus EF, Donders K, Hoffman HG, and Schooler JW (1989) Creating new memories that are quickly accessed and confidently held. *Mem. Cogn.* 17: 607–616.
MacLin MK (2002) The effects of exemplar and prototype descriptors on verbal overshadowing. *Appl. Cogn. Psychol.* 16: 929–936.
Mäntylä T (1986) Optimizing cue effectiveness: Recall of 500 and 600 incidentally learned words. *J. Exp. Psychol. Learn. Mem. Cogn.* 12: 66–71.
Marsh EJ and Dolan PO (2007) Test-induced priming of false memories. *Psychon. Bull. Rev.* 14: 479–483.
Mazzoni GAL, Loftus EF, and Kirsch I (2001) Changing beliefs about implausible autobiographical events: A little plausibility goes a long way. *J. Exp. Psychol. Appl.* 7: 51–59.
McDermott KB and Roediger HL III (1998) Attempting to avoid illusory memories: Robust false recognition on associates persists under conditions of explicit warnings and immediate testing. *J. Mem. Lang.* 39: 508–520.
McDermott KB and Watson JM (2001) The rise and fall of false recall: The impact of presentation duration. *J. Mem. Lang.* 45: 160–176.
McGeoch JA (1932) Forgetting and the law of disuse. *Psychol. Rev.* 39: 352–370.
Meissner CA and Brigham JC (2001) A meta-analysis of the verbal overshadowing effect in face identification. *Appl. Cogn. Psychol.* 15: 603–616.
Melcher JM and Schooler JW (1996) The misremembrance of wines past: Verbal and perceptual expertise differentially mediate verbal overshadowing of taste memory. *J. Mem. Lang.* 35: 231–245.
Mitchell KJ and Zaragoza MS (1996) Repeated exposure to suggestion and false memory: The role of contextual variability. *J. Mem. Lang.* 35: 246–260.
Multhaup KS (1995) Aging, source, and decision criteria: When false fame errors do and do not occur. *Psychol. Aging* 10: 492–497.
Multhaup KS and Conner CA (2002) The effects of considering nonlist sources on the Deese-Roediger-McDermott memory illusion. *J. Mem. Lang.* 47: 214–228.
Nickerson RS and Adams MJ (1979) Long-term memory for a common object. *Cogn. Psychol.* 11: 287–307.
Paddock JR, Noel M, and Terranova S (1999) Imagination inflation and the perils of guided visualization. *J. Psychol. Interdiscip. Appl.* 133: 581–595.
Payne DG, Elie CJ, Blackwell JM, and Neuschatz JS (1996) Memory illusions: Recalling, recognizing, and recollecting events that never occurred. *Special Issue: Illusions of Memory. J. Mem. Lang.* 35: 261–285.
Pendergrast M (1996) *Victims of Memory: Sex Abuse Accusations and Shattered Lives*. Hinesburg, VT: Upper Access.
Perfect TJ, Hunt LJ, and Harris CM (2002) Verbal overshadowing in voice recognition. *Appl. Cogn. Psychol.* 16: 973–980.
Peters MJV, Horselenberg R, and Jelicic M (2007) The false fame illusion in people with memories about a previous life. *Conscious. Cogn.* 16: 162–169.
Pezdek K (1977) Cross-modality semantic integration of sentence and picture memory. *J. Exp. Psychol. Hum. Learn. Mem.* 3: 515–524.
Pezdek K, Finger K, and Hodge D (1997) Planting false childhood memories: The role of event plausibility. *Psychol. Sci.* 8: 437–441.
Raz N (2000) Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In: Craik FIM and Salthouse TA (eds.) *Handbook of Aging and Cognition,* 2nd edn., pp. 1–90. Mahwah, NJ: Erlbaum.
Read JD (1996) From a passing thought to a false memory in 2 minutes: Confusing real and illusory events. *Psychon. Bull. Rev.* 3: 105–111.
Rinck M (1999) Memory for everyday objects: Where are the digits on numerical keypads? *Appl. Cogn. Psychol.* 13: 329–350.
Robbins LC (1963) The accuracy of parental recall of aspects of child development and child rearing practices. *J. Abnorm. Soc. Psychol.* 66: 261–270.
Robinson KJ and Roediger HL III (1997) Associative processes in false recall and false recognition. *Psychol. Sci.* 8: 231–237.
Roediger HL III (1996) Memory illusions. *J. Mem. Lang.* 35: 76–100.
Roediger HL III and McDermott KB (1995) Creating false memories: Remembering words not presented in lists. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 803–814.

Roediger HL III, Jacoby JD, and McDermott KB (1996) Misinformation effects in recall: Creating false memories through repeated retrieval. *Special Issue: Illusions of Memory. J. Mem. Lang.* 35: 300–318.
Roediger HL III, Meade ML, and Bergman ET (2001a) Social contagion of memory. *Psychon. Bull. Rev.* 8: 365–371.
Roediger HL III, Watson JM, McDermott KB, and Gallo DA (2001b) Factors that determine false recall: A multiple regression analysis. *Psychon. Bull. Rev.* 8: 385–407.
Santa JL and Ranken HB (1972) Effects of verbal coding on recognition memory. *J. Exp. Psychol.* 93: 268–278.
Schacter DL, Israel L, and Racine C (1999) Suppressing false recognition in younger and older adults: The distinctiveness heuristic. *J. Mem. Lang.* 40: 1–24.
Schooler JW (2002) Verbalization produces a transfer inappropriate processing shift. *Appl. Cogn. Psychol.* 16: 989–997.
Schooler JW and Engstler-Schooler TY (1990) Verbal overshadowing of visual memories: Some things are better left unsaid. *Cogn. Psychol.* 22: 36–71.
Schooler JW, Gerhard D, and Loftus EF (1986) Qualities of the unreal. *J. Exp. Psychol. Learn. Mem. Cogn.* 12: 171–181.
Sharman SJ, Garry M, and Beuke CJ (2004) Imagination or exposure causes imagination inflation. *Am. J. Psychol.* 117: 157–168.
Sharman SJ, Manning CG, and Garry M (2005) Explain this: Explaining childhood events inflates confidence for those events. *Appl. Cogn. Psychol.* 19: 67–74.
Shepard RN (1967) Recognition memory for words, sentences, and pictures. *J. Verb. Learn. Verb. Behav.* 6: 151–163.
Sommers MS and Lewis BP (1999) Who really lives next door: Creating false memories with phonological neighbors. *J. Mem. Lang.* 40: 83–108.
Thomas AK, Bulevich JB, and Loftus EF (2003) Exploring the role of repetition and sensory elaboration in the imagination inflation effect. *Mem. Cogn.* 31: 630–640.
Tousignant JP, Hall D, and Loftus EF (1986) Discrepancy detection and vulnerability to misleading postevent information. *Mem. Cogn.* 14: 329–338.
Tulving E (1983) *Elements of Episodic Memory*. New York: Oxford University Press.
Wade KA, Garry M, Read JD, and Lindsay DS (2002) A picture is worth a thousand lies: Using false photographs to create false childhood memories. *Psychon. Bull. Rev.* 9: 597–603.
Watson JM, Balota DA, and Roediger HL III (2003) Creating false memories with hybrid lists of semantic and phonological associates: Over-additive false memories produced by converging associative networks. *J. Mem. Lang.* 49: 95–118.
Wells GL, Memon A, and Penrod SD (2006) Eyewitness evidence: Improving its probative value. *Psychol. Sci. Public Interest* 7: 45–75.
Westerman DL and Greene RL (1996) On the generality of the revelation effect. *J. Exp. Psychol. Learn. Mem. Cogn.* 22: 1147–1153.
Witherspoon D and Allan LG (1985) The effects of a prior presentation on temporal judgments in a perceptual identification task. *Mem. Cogn.* 13: 101–111.
Wright DB, Varley S, and Belton A (1996) Accurate second guesses in misinformation studies. *Appl. Cogn. Psychol.* 10: 13–21.
Wright DB, Mathews SA, and Skagerberg EM (2005) Social recognition memory: The effect of other people's responses for previously seen and unseen items. *J. Exp. Psychol.* 11: 200–209.
Zaragoza MS and Lane SM (1994) Source misattributions and the suggestibility of eyewitness memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 934–945.
Zaragoza MS and Mitchell KJ (1996) Repeated exposure to suggestion and the creation of false memories. *Psychol. Sci.* 7: 294–300.

# 2.15 Memory in and about Affect

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Philosophers, politicians, and playwrights alike have recognized for centuries the capacity of moods to color the way people remember the past, experience the present, and forecast the future. Psychologists, however, were relatively late to acknowledge this reality, despite a number of promising early leads (e.g., Rapaport, 1942/1961; Razran, 1940). Indeed, it is only within the past 30 years that empirical investigations of the interplay between affect and cognition have been published with regularity in mainstream psychology journals (see LeDoux, 1996).

Psychology's late start in exploring the affect–cognition interface reflects the fact that neither behaviorism nor cognitivism – the two paradigms that dominated the discipline throughout the twentieth century – ascribed much importance to affective phenomena, whether in the form of specific, short-lived emotional reactions or more nebulous, long-lasting mood states (for detailed discussion of affect-related concepts, see Russell and Feldman Barrett, 1999; Russell and Lemay, 2000).

From the perspective of the radical behaviorist, all unobservable mental events, including those affective in nature, were by definition deemed beyond the bounds of scientific psychology. Though early behaviorist research examined the environmental conditioning of emotional responses, later studies focused mainly on the behavioral consequences of readily manipulated drive states, such as thirst or fear. In such studies, emotion was instilled in animals through crude if effective means, such as electric shock, and emotionality was operationalized by counting the number of fecal boluses deposited by small, scared animals. As a result, behaviorist research and theory added little to our understanding of the interrelations between affect and cognition.

Until recently, the alternative cognitive paradigm also had little interest in affective phenomena. To the extent that the cognitive revolutionaries of the early 1960s considered affects at all, they typically envisaged them as disruptive influences on 'proper' – read 'emotionless' or 'cold' – thought processes. Thus, the transition from behaviorism to cognitivism allowed psychology to reclaim its head, but did nothing to recapture its heart.

Things are different today. Affect is now known to play a key role in how information about the world is processed and represented. Moreover, affect underlies the cognitive representation of social experience (Bower and Forgas, 2000), and emotional responses can serve as an organizing principle in cognitive categorization (Niedenthal and Halberstadt, 2000). Thus, the experience of affect – how we feel about people, places, and events – is central to people's cognitive representations of themselves and the world around them.

When it comes to memory, a major theme of this book, two overarching questions are of interest. One of these concerns memory 'in' affect: How do affective states or moods influence the acquisition and retention of information? The other question involves memory 'about' affect: What determines the accuracy and other attributes of memory for emotionally charged events? Over the past 30 years, both questions have been pursued with a wide array of subject species (humans, mice, mollusks, etc.), scientific approaches (experiential, physiological, neuroimaging), and memory methods (different materials, tasks, and measures). In addition, each of these highly general questions subsumes a host of more specific issues, including such varied topics as the consistency of flashbulb recollections (Talarico and Rubin, 2003), cognitive and clinical investigations of mood-dependent memory (Eich and Macaulay, 2006), dissociable influences of affective valence and arousal on memory vividness (Kensinger and Corkin, 2004; Kensinger and Schacter, 2006), and neural systems underlying the encoding and retrieval of emotional events in animals and humans (LaBar and Cabeza, 2006; Phelps, 2006).

This chapter surveys only a small segment of the vast affect/memory literature and its scope is limited to human cognitive and social research. Whereas the first part of the chapter covers mood-congruent cognition, a concept that is central to understanding how affective states influence memory, the second part focuses on memory for trauma, a controversial topic with important implications both for cognitive theory and for clinical practice. Given that mood congruence has had little overlap, conceptually or methodologically, with research on memory for traumatic events, our approach will be to treat memory in and about affect as distinct topics. Nevertheless, consideration of these topics together invites exploration of the possible empirical and theoretical issues that might unite them. To this end, we close with a discussion of potential ways in which the principles and findings of mood congruence might apply to understanding the processes leading to reports of recovered memories of trauma.

## 2.15.1 Memory in Affect

People often acquire, remember, and interpret information about themselves, and the world around them, in a manner that matches their current state of affect or mood. However, these mood-congruent effects are not universal, but depend for their expression on a variety of task-, person-, and situation-specific variables (Bower and Forgas, 2000). Since the early 1980s, a great deal of effort has gone into explaining why mood-congruent effects are robust and reliable under certain circumstances, but weak or nonexistent under others. The fruits of this effort are the focus of discussion in this part of the chapter.

We begin by introducing the concepts of affect priming and affect-as-information, both of which are central in understanding the impact of moods on the substance of cognition, or what people think. Attention then turns to the processing consequences of affect, that is, the impact of moods on cognitive style, or how people think. These opening remarks on cognitive substance versus style will set the stage for discussion of an integrative theory – Forgas's (1995, 2002) affect infusion model (AIM) – that seeks to specify the ways in which affect influences cognition in general and social cognition in particular. Next we consider the critical part that different information processing strategies play in the occurrence of mood congruence, and we conclude this section by summarizing some of the strengths and shortcomings of the AIM.

#### 2.15.1.1 Affect Priming and Affect-as-Information

Several theorists maintain that moods influence the content of cognition because they influence the memory structures people rely on when processing information. For example, Wyer and Srull (1989) suggested that recently activated concepts are more accessible because such concepts are returned to the top of mental storage bins, which in turn means that subsequent sequential searches are more likely to access the same concepts again. As affective states facilitate the use of positively or negatively valenced mental concepts, this could account for the greater use of mood-congruent constructs in subsequent tasks.

A more comprehensive explanation of this effect was provided by Bower's (1981) associative network model. On this view, the observed links between affect and cognition are neither motivationally based (cf. the psychoanalytic theory of Feshback and Singer, 1957), nor are they the result of merely incidental, spatiotemporal associations (cf. the conditioning theory of Byrne and Clore, 1970). Instead, Bower (1981) argued that affect is integrally linked to an associative network of mental representations. Accordingly, the activation of an affective state should selectively and automatically prime associated thoughts and representations previously linked to that affect, and these concepts should be more likely to be used in subsequent constructive cognitive tasks.

Consistent with the network model, early studies provided strong support for the concept of affective priming, indicating mood congruence across a wide range of cognitive tasks. For example, people induced to feel good or bad tend to selectively remember more mood-congruent details from their childhood and more of the real-life events they had recorded in a daily diary for a week (Bower, 1981). Mood congruence was also observed in subjects' interpretations of social behaviors and in their impressions of other people (Bower and Forgas, 2000).

However, subsequent research showed that mood congruence is subject to several boundary conditions (see Blaney, 1986; Bower, 1987; Singer and Salovey, 1988). Difficulties in demonstrating reliable mood-congruent effects were ascribed to such varied causes as the lack of sufficiently strong or intense moods (Bower and Mayer, 1985), the subjects' inability to perceive a meaningful, causal connection between their current mood and the cognitive task they are asked to perform (Bower, 1991), and the use of tasks that prevent subjects from processing the target material in a self-referential manner (Blaney, 1986). Interestingly, mood-congruent effects tend to be more reliably obtained when complex and realistic materials are used in conjunction with tasks (e.g., association generation, impression formation, or inference making) that require a high degree of open, constructive processing (e.g., Bower and Forgas, 2000; Mayer et al., 1992). Such tasks provide people with a rich set of encoding and retrieval cues and thus allow affect to more readily function as a differentiating context (Bower, 1992). A similar point was made by Fiedler (1991), who suggested that mood congruence may obtain only in constructive cognitive tasks – those that involve an open-ended search for information (as in recall tasks) and the active elaboration and transformation of stimulus details using existing knowledge structures (as in judgmental and inferential tasks).

It appears, then, that affect priming occurs when an existing affective state preferentially activates and facilitates the use of affect-consistent information from memory in a constructive cognitive task. The consequence of affect priming is affect infusion: The tendency for judgments, memories, thoughts, and behaviors to become more mood congruent (Forgas, 1995, 2002). But in order for such infusion effects to emerge, it is important that subjects adopt an open, elaborate information processing strategy that facilitates the incidental use of affectively primed memories and information. Thus, the nature and extent of affective influences on memory and cognition should largely depend on what kind of information processing strategy people employ in a particular situation. Later we will review the empirical evidence for this prediction and describe an integrative theory that emphasizes the role of information-processing strategies in moderating mood congruence.

Alternatively, the affect-as-information (AAI) model of Schwarz and Clore (1983, 1988) suggests that "rather than computing a judgment on the basis of recalled features of a target, individuals may . . . ask themselves: 'How do I feel about it? [and] in doing so, they may mistake feelings due to a pre-existing state as a reaction to the target" (Schwarz, 1990: 529). Thus, the model implies that mood congruence in judgments is due to an inferential error, as people misattribute a preexisting affective state to a judgmental target.

The AAI model incorporates ideas from three past research traditions. First, the predictions of the model are often indistinguishable from earlier conditioning research by Clore and Byrne (1974). Whereas the conditioning account claimed that spatiotemporal contiguity is chiefly responsible for linking affect to judgments, the AAI model posits an internal inferential process as producing the same effects (see Berkowitz et al., 2000). A second tradition that informs the AAI model comes from research on misattribution, according to which judgments are often inferred on the basis of salient but irrelevant heuristic cues – in this case, affective state. Thus, the AAI model also predicts that only previously unattributed affect can produce mood congruence. Finally, the model also shows some affinity with research on judgmental heuristics, insofar as affective states are thought to function as heuristic cues in informing people's judgments.

People typically rely on affect as a heuristic cue when they lack either or both the motivation and the cognitive resources to process information more extensively. This happens when "the task is of little personal relevance, when little other information is available, when problems are too complex to be solved systematically, and when time or attentional resources are limited" (Fiedler, 2001: 175). For example, some of the earliest and still most compelling evidence for the AAI model came from an experiment (Schwarz and Clore, 1983) that involved telephoning respondents and asking them unexpected and unfamiliar questions. In this situation, subjects have little personal interest or involvement in responding to a stranger, and they have neither the motivation, the time, nor the cognitive resources to engage in extensive processing. Relying on prevailing affect to infer a response seems a reasonable strategy under such circumstances. In a conceptually similar example, Forgas and Moylan (1987) asked people to complete an attitude survey on the sidewalk outside a cinema in which they had just watched either a happy or a sad movie. The results showed strong mood congruence: Happy theatergoers gave much more positive responses than did their sad counterparts. In this situation, as in the study by Schwarz and Clore (1983), respondents presumably had insufficient time, motivation, or capacity to engage in elaborate processing, and hence they may well have relied on their temporary affect as a heuristic cue to infer a reaction. Thus, depending on the task, situation, and resources at hand, either affect priming or AAI can take the lead in coloring or infusing cognition with current affect.

#### 2.15.1.2 Processing Consequences of Affect

Affective states or moods shape not only the substance of cognition but also its style. It has been proposed that positive affect recruits less effortful and more superficial processing strategies; in contrast, negative affect seems to trigger a more analytic and vigilant processing style (Clark and Isen, 1982; Schwarz, 1990; Mackie and Worth, 1991). However, more recent studies have shown that positive affect can also produce distinct processing advantages: Happy people often adopt more creative and inclusive thinking styles and display greater mental flexibility than do sad subjects (Bless, 2000; Fiedler, 2000; Isen, 2004).

Several theories have sought to explain affective influences on processing strategies. One suggestion is that the experience of a negative mood, or any affective state, gives rise to intrusive, irrelevant thoughts that deplete attentional resources, which in turn leads to poor performance in a variety of cognitive tasks (Ellis and Ashbrook, 1988; Ellis and Moore, 1999). An alternative hypothesis points to the motivational consequences of positive and negative affect: Whereas people experiencing positive affect may try to maintain a pleasant state by refraining from any effortful activity, negative affect may motivate people to engage in vigilant, effortful processing (Isen, 1984). In a variation of this idea, Schwarz (1990) has suggested that affective states have a signaling or tuning function, informing the person that relaxed, effort-minimizing processing is appropriate in the case of positive affect, whereas vigilant, effortful processing is best suited for negative affect.

These various accounts all assume that positive and negative affect decrease or increase the effort, vigilance, and elaborateness of information processing, albeit for different reasons. Recently, Bless and Fiedler (2006) have conjectured that the evolutionary significance of positive and negative affect is not simply to influence processing effort, but to trigger two fundamentally different processing styles. They suggest that positive affect promotes a more schema-based, top-down, assimilative processing style, whereas negative affect produces a more bottom-up, externally focused, accommodative processing strategy.

These strategies can be equally vigilant and effortful, yet produce markedly different cognitive outcomes by directing attention to internal or external sources of information.

These affect-induced processing differences may well have evolutionary origins, consistent with the idea that the basic function of affective states is to rapidly trigger cognitive strategies most likely to produce adaptive responses to a situation (Frijda, 1986). In other words, affect may operate like domain-specific adaptation that meets the requirements for special design (Haselton and Ketelaar, 2006; also see Forgas et al., 2007).

#### 2.15.1.3 Cognitive Benefits of Mild Dysphoria for Eyewitness Memory

Another perspective on the processing consequences of affect is provided by recent research showing that affect-induced differences in processing style have major implications for memory and memory-based social cognitive tasks, including some surprising cognitive advantages associated with mild dysphoria.

For example, a recent series of studies revealed a beneficial effect of negative affect on eyewitness memory (Forgas et al., 2005). Affect can impact eyewitness memory at any or all of three distinct stages: (1) when the event is first witnessed (encoding stage), (2) when misleading information is encountered later on (post-event stage), and (3) when the information is retrieved (retrieval stage). Several experiments examined mood effects at Stage 2 and found that positive affect promoted, and negative affect inhibited, the incorporation of false details into eyewitness memories (Forgas et al., 2005), consistent with the more attentive, accommodative processing style associated with negative affect that may have helped witnesses to identify misleading details when exposed to them (Bless and Fiedler, 2006).

In one study (Forgas et al., 2005, Experiment 1), participants viewed pictures showing a car crash scene (negative event) and a wedding party scene (positive event). One hour later, following the induction of a happy, sad, or neutral mood, participants completed a questionnaire about the scenes that either contained or did not contain misleading information. In this particular study, moods were induced by asking participants to reflect upon, write about, and emotionally relive either a positive, neutral, or negative experience from their personal past. In addition to this life-events technique, many other methods of mood modification (involving videos, music, guided

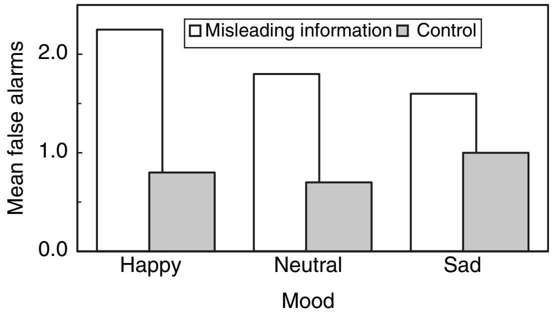


**Figure 1** Mean false alarms to misleading postevent information as a function of participants' mood (happy, neutral, or sad) and condition (misleading information previously presented versus control). From Forgas JP, Vargas P, and Laham S (2005) Mood effects on eyewitness memory: Affective influences on susceptibility to misinformation. *J. Exp. Soc. Psychol.* 41: 574–588; Experiment 1; used with permission from Elsevier.

imagery, etc.) are available to investigators in the affect/cognition area (see Coan and Allen, 2007). After an additional interval filled with other tasks, the accuracy of their eyewitness memory for the scenes was tested. As predicted, and as indicated in **Figure 1**, exposure to misleading information significantly reduced eyewitness accuracy, an effect that, remarkably, was increased by positive mood and decreased by negative mood. In fact, negative mood almost completely eliminated the familiar misinformation effect.

In a second study (Forgas et al., 2005, Experiment 2), students in a lecture hall witnessed a staged aggressive encounter between a lecturer and a female intruder. One week later, eyewitnesses to this episode were induced into a positive or negative mood and then completed a questionnaire about the episode that either did or did not contain planted, misleading information. When the accuracy of their eyewitness memory for the episode was subsequently tested, negative affect again seemed to have all but eliminated this source of error in eyewitness memory. Signal detection analyses confirmed that negative affect actually improved eyewitnesses' ability to discriminate between correct and misleading details.

Can people suppress the impact of their moods on their thinking when instructed to do so? In a third study (Forgas et al., 2005, Experiment 3), participants watched a videotape of a complex event (a wedding or a convenience-store robbery). After viewing a happy or sad videotape, they completed a short questionnaire that either did or did not contain misleading information. Some participants were also instructed to disregard and control their current affective state. Exposure to misleading information again reduced eyewitness accuracy, and did so most when people were in a happy rather than a sad mood. Instructions to control affect did not reduce this mood effect, but rather, produced an overall conservative response bias.

These experiments offer convergent evidence that negative moods can have significant adaptive effects on memory and cognitive performance, by promoting a more focused, accommodative processing style that reduced people's susceptibility to misleading information and thus improved eyewitness memory. These results are consistent with theories that predict that good and bad moods should have an asymmetric effect on processing strategies and outcomes (Forgas, 1995, Bless, 2000; Forgas, 2002).

### 2.15.1.4 Mood Congruence and the Affect Infusion Model

We have seen that affective states have clear if complex effects on both the substance of cognition (i.e., the contents of one's thoughts) and its style (e.g., whether information is processed systematically or superficially). It is also clear, however, that affective influences on cognition are context-specific. A comprehensive explanation of these effects needs to specify the circumstances that promote or impede mood congruence, and should also define the conditions likely to trigger either affect priming or affect-as-information mechanisms.

The AIM (Forgas, 1995) seeks to accomplish these goals by expanding on Fiedler's (1991) idea that mood congruence is most likely to occur when circumstances call for an open, constructive style of information processing. Such a style involves the active elaboration of the available stimulus details and the use of memory-based information in this process. The AIM thus predicts that (1) the extent and nature of affect infusion should be dependent on the kind of processing strategy that is used, and (2) all things being equal, people should use the least effortful and simplest processing strategy capable of producing a response. As this model has been described in detail elsewhere (Forgas, 1995, 2002), only a brief overview will be provided here.

The AIM identifies four processing strategies that vary according to both the degree of openness or constructiveness of the information-search strategy and the amount of effort exerted in seeking a solution. The direct access strategy involves the retrieval of preexisting responses and is most likely when the task is highly familiar and when no strong situational or motivational cues call for more elaborate processing. For example, if you were asked to make an evaluative judgment about a well-known political leader, a previously computed and stored response would come quickly and effortlessly to mind, assuming that you had thought about this topic extensively in the past. People possess a rich store of such preformed attitudes and judgments. Given that such standard responses require no constructive processing, affect infusion should not occur.

The motivated processing strategy involves highly selective and targeted thinking that is dominated by a particular motivational objective. This strategy should be impervious to affect infusion (Clark and Isen, 1982) and may produce mood-incongruent outcomes when the motivation is to control or reverse affect congruence (Forgas and Ciarrochi, 2002). For instance, if in a job interview you are asked about your attitude toward the company you want to join, the response will be dominated by the motivation to produce an acceptable response. Open, constructive processing is inhibited and affect infusion is unlikely to occur. The consequences of motivated processing should depend on the particular processing goal and may also produce a reversal of mood-congruent effects (Berkowitz et al., 2000).

The remaining two processing strategies require more constructive and open-ended information search strategies, and thus facilitate affect infusion. Heuristic processing is the kind of superficial, quick processing style people are likely to adopt when they lack motivation or resources to process more extensively (Schwarz and Clore, 1983; Forgas and Moylan, 1987). Heuristic processing can lead to affect infusion as long as people rely on affect as a simple inferential cue and depend on the 'how do I feel about it' heuristic to produce a response (Schwarz and Clore, 1988; Clore et al., 2001).

When simpler strategies such as direct access, motivated processing, or heuristic processing prove inadequate, people need to engage in substantive processing to satisfy the demands of the task at hand. According to the AIM, substantive processing should be adopted when (1) the task is in some ways demanding, atypical, complex, novel, or personally relevant, (2) there are no direct-access responses available, (3) there are no clear motivational goals to guide processing, and (4) adequate time and other processing resources are available. Substantive processing is an inherently open and constructive strategy, and affective states may selectively prime or enhance the accessibility of related thoughts, memories, and interpretations. The model makes the interesting and counterintuitive prediction that affect infusion – and hence mood congruence – should be increased when extensive and elaborate processing is required to deal with a more complex, demanding, or novel task. This prediction has been borne out by several studies that will be summarized shortly.

The AIM also specifies a range of contextual variables related to the task, the person, and the situation that jointly influence processing choices. For example, greater task familiarity, complexity, and typicality should recruit more substantive processing. Personal characteristics that influence processing style include motivation, cognitive capacity, and personality traits such as self-esteem (Smith and Petty, 1995; Rusting, 2001). Situational factors that influence processing style include social norms, public scrutiny, and social influence by others (Forgas, 1995).

An important feature of the AIM is that it recognizes that affect itself can also influence processing choices. As noted earlier, Bless and Fiedler (2006) have proposed that positive affect typically generates a more assimilative, top-down, schema-driven processing style whereby new information is assimilated into what is already known. In contrast, negative affect often promotes a more accommodative, piecemeal, bottom-up processing strategy in which attention to external events dominates over existing stored knowledge.

The key prediction of the AIM is the absence of affect infusion when direct access or motivated processing is used and the presence of affect infusion during heuristic and substantive processing. The implications of this model have been investigated in many studies involving several substantive areas in which mood congruence has been demonstrated, including affective influences on attention, learning, memory, and social cognition. The following subsections present a snapshot of some of these studies and areas.

#### 2.15.1.4.1 Mood congruence in attention and learning

Many everyday cognitive tasks are performed under conditions of considerable information overload, when people need to select a small sample of information for further processing. Affect may have a significant influence on what people will pay attention to and learn (Niedenthal and Setterlund, 1994). Due to the selective activation of an affect-related associative base, mood-congruent information may receive greater attention and be processed more extensively than affectively neutral or incongruent information (Bower, 1981; Bower and Cohen, 1982). Several studies have shown that people spend longer reading mood-congruent material, linking it into a richer network of primed associations; as a result, they are better able to remember such information (Bower and Forgas, 2000).

These effects occur because "concepts, words, themes, and rules of inference that are associated with that emotion will become primed and highly available for use . . . [in] . . . top-down or expectation-driven processing . . . [acting] . . . as interpretive filters of reality" (Bower, 1983: 395). Thus, there is a tendency for people to process mood-congruent material more deeply, with greater associative elaboration, and thus learn it better. Consistent with this notion, depressed psychiatric patients tend to learn and remember depressive words particularly well, a cognitive bias that disappears once the depressive episode is over (Bradley and Mathews, 1983; Watkins et al., 1992). However, mood-congruent learning is seldom seen in patients suffering from anxiety (Watts and Dalgleish, 1991; Burke and Mathews, 1992), perhaps because anxious people tend to use particularly vigilant, motivated processing strategies to defend against anxiety-arousing information (Mathews and MacLeod, 1994; Ciarrochi and Forgas, 1999). Thus, as predicted by the AIM, different processing strategies appear to play a critical role in mediating mood congruence in learning and attention.

#### 2.15.1.4.2 Mood congruence in memory

Several studies have shown that people are better able to consciously or explicitly recollect autobiographical memories that match their prevailing mood (Bower, 1981). Depressed patients display a similar pattern, preferentially remembering aversive childhood experiences, another kind of cognitive bias that disappears once depression is brought under control (Lewinsohn and Rosenbaum, 1987). In line with the AIM, these mood-congruent effects also emerge when people try to recall complex social stimuli (Fiedler, 1991; Forgas, 1993).

Research using implicit tests of memory, which do not require conscious recollection of past experience, also provides evidence of mood congruence. For example, depressed people tend to complete more word stems (e.g., ‘can’) with negative than with positive words they have studied earlier (e.g., ‘cancer’ vs. ‘candy’; Ruiz-Caballero and Gonzalez, 1994). Similar results have been obtained in other studies involving experimentally induced states of happiness or sadness (Tobias et al., 1992).

#### 2.15.1.4.3 Mood congruence in associations and interpretations

Cognitive tasks often require people to go beyond the information given, forcing them to rely on associations, inferences, and interpretations to construct a judgment or a decision, particularly when dealing with complex and ambiguous social information (Heider, 1958). Affect can prime the kind of associations used in the interpretation and evaluation of a stimulus (Clark and Waddell, 1983).

The greater availability of mood-congruent associations can have a marked influence on the top-down, constructive processing of complex or ambiguous details (Bower and Forgas, 2000). For example, when asked to freely associate to the cue ‘life,’ happy subjects generate more positive than negative associations (e.g., ‘love, freedom’ vs. ‘struggle, death’), whereas sad subjects do the opposite (Bower, 1981). In a related vein, mood-congruent associations emerge when emotional subjects daydream or concoct stories about fictional characters depicted in the Thematic Apperception Test (Bower, 1981). Mood-primed associations also play an important role in clinical states: Anxious people tend to interpret spoken homophones such as pane/pain or dye/die in the more anxious, negative direction (Eysenck et al., 1987), consistent with the greater activation these mood-congruent concepts receive.

Such mood-congruent effects can have a marked impact on many types of social judgments, including perceptions of human faces (Schiffenbauer, 1974), impressions of people (Bower and Forgas, 2000), and self-perceptions (Sedikides, 1995). However, several studies have shown that this associative effect is diminished as the targets to be judged become more clear-cut and thus require less constructive processing (Forgas, 1995). Such a diminution in the associative consequences of mood with increasing stimulus clarity again suggests that open, constructive processing is crucial for mood congruence to occur. This same mechanism also leads to mood congruence in more complex and elaborate social judgments, such as judgments about the self and others, as the results sketched in the following section suggest.

#### 2.15.1.4.4 Mood congruence in self-judgments

Affective states have a strong assimilative influence on memory-based judgments about the self: Positive affect improves and negative affect impairs the valence of self-conceptions. In one study (Forgas et al., 1990), happy or sad students who had scored well or poorly on a recent exam were asked to rate the extent to which their test performance was attributable to factors that were internal in origin and stable over time. Compared to their negative mood counterparts, students in a positive mood were more likely to claim credit for success, making more internal and stable attributions for high test scores, but less willing to assume personal responsibility for failure, making more external and unstable attributions for low test scores.

Of related interest is a study by Sedikides (1995), who asked subjects to evaluate a series of self-descriptions related to their behaviors or personality traits while they were in a happy, sad, or neutral mood. Based on the AIM, Sedikides predicted that highly rehearsed core conceptions of the self should be processed quickly using the direct-access strategy and hence should show no mood-congruent bias; in contrast, less salient, peripheral self-conceptions should require more time-consuming substantive processing and accordingly be influenced by an affect-priming effect. The results supported these predictions, making Sedikides’ (1995) research the first to demonstrate differential mood-congruent effects for central versus peripheral conceptions of the self.

Affect also appears to have a greater congruent influence on self-related memories and judgments made by people with low versus high self-esteem, which may reflect a parallel difference in the stability of their respective self-concepts (Brown and Mankowski, 1993). For instance, Smith and Petty (1995) observed stronger mood congruence in the self-related memories reported by low rather than high self-esteem individuals. As predicted by the AIM, these findings suggest that low self-esteem people need to engage in more open and elaborate processing when thinking about themselves, increasing the tendency for their current mood to influence the outcome.

Affect intensity may be another moderator of mood congruence. One study showed that mood congruence is greater among people who score high on measures assessing openness-to-feelings as a personality trait (Ciarrochi and Forgas, 2000). However, other studies suggest that mood congruence in self-related memories and judgments can be spontaneously reversed as a result of motivated processing strategies. Sedikides (1994) observed that after mood induction, people initially generated self-statements in a mood-congruent manner. However, with the passage of time, negative self-judgments spontaneously reversed, suggesting the operation of an automatic process of mood management. Research by Forgas and Ciarrochi (2002) replicated these results and indicated further that the spontaneous reversal of negative self-judgments is particularly rapid and pronounced in people with high self-esteem.

In summary, moods have been shown to exert a strong congruent influence on self-related memories and judgments, but only when some degree of open and constructive processing is required and when there are no motivational forces to override mood congruence. Research to date also indicates that the infusion of affect into self-judgments is especially likely when these judgments (a) relate to peripheral in contrast to central aspects of the self, (b) require extensive, time-consuming processing, and (c) reflect the self-conceptions of individuals with low rather than high self-esteem.

#### 2.15.1.4.5 Mood congruence in person perception

The AIM predicts that the more people need to think in order to compute a response, the greater the likelihood that affectively primed ideas will influence the outcome. To test this prediction, several researchers have manipulated the complexity of the subjects' task in order to create more or less demand for elaborate processing.

In one set of studies (Forgas, 1992), happy and sad participants were asked to read and form impressions about fictional characters who were described as being highly typical or highly atypical and having an odd combination of attributes (e.g., an avid surfer whose favorite music is Italian opera). The expectation was that when people have to form an impression about a complex, ambiguous, or atypical individual, they will need to engage in more constructive processing and affectively primed associations should thus have a greater chance to infuse the judgmental outcome.

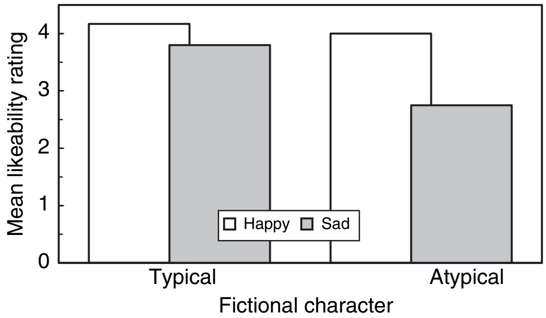


**Figure 2** Impact of participants' mood on their ratings of the likeability of typical or atypical fictional characters. From Forgas JP (1992) On bad mood and peculiar people: Affect and person typicality in impression formation. *J. Pers. Soc. Psychol.* 62: 863–875; Experiment 3; used with permission from the American Psychological Association.

Consistent with this reasoning, participants took longer to read about unusual as opposed to conventional characters. Moreover, mood-congruent effects were more pronounced when happy and sad participants judged the likeability of atypical in contrast to typical fictional characters, a finding depicted in **Figure 2**. Similar results were found in a follow-up study in which the to-be-judged targets were odd versus ordinary couples rather than individuals (Forgas, 1993).

Research investigating the impact of mood on judgments and inferences about real-life interpersonal issues paints a similar picture. For example, partners in long-term, intimate relationships showed clear evidence of mood congruence in their memories and attributions for actual conflicts, and paradoxically, these effects were greater when thinking about more serious conflicts that required more extensive processing (Forgas, 1995). These results provide direct evidence for the process dependence of affect infusion into social judgments and inferences. Even judgments about highly familiar people are more prone to affect infusion when a more substantive processing strategy is used.

Some individual-difference or personality characteristics, such as trait anxiety, can also influence processing styles and thereby significantly moderate the influence of negative mood on intergroup judgments (Ciarrochi and Forgas, 1999). Low trait-anxious whites in the United States reacted more negatively to a threatening black out-group when experiencing negative affect. Surprisingly, high trait-anxious individuals showed the opposite pattern: They went out of their way to control their negative tendencies when feeling bad and produced more positive judgments. Thus it appeared that low trait-anxious people allowed affect to influence their judgments, while high trait-anxiety combined with aversive mood triggered a more controlled, motivated processing strategy designed to eliminate socially undesirable intergroup judgments.

### 2.15.1.5 Strengths and Shortcomings of the Affect Infusion Model

To recap, the AIM attempts to account for mood-congruent effects in social cognition (Forgas, 1995). It provides a means of integrating two explanations of mood effects, namely AAI (Schwarz and Clore, 1988) and affect priming (Bower, 1981). It outlines the situations in which each process dominates and therefore is the primary method for affect to influence people's thoughts and behaviors. The model accounts well for mood effects on learning and memory (Bower and Forgas, 2000) and a wide array of affective influences on social cognition, including perceptions of others as well as oneself.

The AIM also casts light on the conditions that are more or less likely to evidence mood-congruent effects. Specifically, when processing is easy and familiar, current mood has less of an impact on task performance than when processing is more demanding, more difficult, and more unusual. Hence, it is precisely when people are paying greater attention, considering carefully, and exerting more cognitive effort that they are likely to be biased by their current, and often unrelated, mood state (Forgas, 1995, 2002).

This pattern of results has an important implication, namely, that such performance differences are more than mere responses to demand characteristics created by experimental mood manipulations, one of the oldest and thorniest issues in contemporary cognition/emotion research (see Polivy and Doyle, 1980; Bower, 1981; Ingram, 1989). Since any demand characteristics that exist should be constant across easy and difficult processing conditions, they cannot be responsible for any behavioral differences that are found between these conditions. Consequently, the greater conceptual precision provided by the AIM makes it a more parsimonious explanation of the data set as a whole.

Though the AIM connects and clarifies data from many domains, several findings are difficult to reconcile with the approach. For instance, the model suggests that negative affect encourages bottom-up, externally focused processing, but the literature on self-focused attention in depression (Pyszczynski and Greenberg, 1987) indicates that negative affect leads to more internally focused processing, proposals that are clearly in conflict.

Another troublesome subject for the AIM is mood *in*congruence, a curious phenomenon that has been seen in several studies involving autobiographical memory, person perception, and other social cognitive tasks. Parrot and Sabini (1990, Experiment 2), for instance, found that college students tended to feel happier on clear than on cloudy days – no surprise there. Yet when asked to recollect a salient experience from their high-school years, the students recalled mostly pleasant events on gloomy days and mostly unpleasant events on sunny days.

The causes of such counterintuitive results remain uncertain. The AIM is chiefly concerned with either the presence or absence of mood-congruent effects, not with the reverse. As mentioned earlier, several researchers have suggested that mood incongruence may be related to an individual's ability and desire to strategically regulate his or her mood (e.g., Sedikides, 1994; Forgas and Ciarrochi, 2002), but other factors may also play an important role.

One such factor was discovered accidentally in research (Eich, 1995) dealing with the mood-mediation theory of place-dependent memory: The idea that how well memorial information transfers from one physical environment (e.g., a sunny courtyard) to a different setting (e.g., a dimly lit room) depends not on how similar the two places look but rather on how similar they feel. On this view, place-dependent effects in human memory represent a special, and rather subtle, form of mood-dependent memory (Eich, 2007).

Participants in two studies (university undergraduates) were asked to recollect or generate as many as 16 specific episodes or events, from any time in the personal past, that were called to mind by neutral noun probes, such as ship and street. After recounting the gist of a given event (what happened, who was involved, etc.), students rated the incident along several dimensions, including its original emotionality: How pleasant or unpleasant the event seemed when it took place. Participants completed this task of autobiographical-event generation in one of two environments: either a small, dark, and spartanly furnished basement office or in a warm, inviting, and exquisitely scenic Japanese garden. The expectation, which was confirmed in both studies, was that students would generally feel happier (more pleasant, more energized) when tested in the latter locale.

Nonetheless, neither experiment provided any evidence of an overall mood-congruent effect: Mean ratings of event emotionality were statistically the same for events that had been generated in the garden versus the office. However, a different picture developed when participants were divided into two groups – aware versus unaware – based on statements they made about the aims and methods of the research in an in-depth postexperimental interview. Whereas participants in the aware group recognized that different environments might evoke different moods, those in the unaware group seemed not to appreciate the possibility of an affect/environment connection.

Among aware subjects, there was clear evidence of mood congruence: Averaging across the two studies, ratings of event emotionality were higher (i.e., more positive) for autobiographical events that had been generated in the garden than in the office. Among unaware subjects, however, the tendency was toward mood incongruence: Events generated in the happy garden were rated as being somewhat less pleasant than those that had been recollected in the sad office.

Additional evidence relating to the awareness factor comes from two recently completed studies (Eich et al., unpublished observations) that were methodologically similar to those outlined earlier in all major respects but one: The frequency with which participants were asked to reflect upon and rate their current mood before, during, and after the task of autobiographical-event generation (which again was carried out in either the garden or office locales). Following the lead of Berkowitz et al. (2000), we reasoned that the very act of assessing one's current mood would enhance awareness of a connection between that mood and the environment in which the assessment is made. In line with this reasoning, the percentage of subjects classified as aware was much higher (63% vs. 29%) in the experiment in which the students evaluated their moods repeatedly than in the otherwise identical experiment in which moods were rated infrequently.

Though it appears that awareness of an affect/environment connection helps determine whether autobiographical memories coincide or contrast with a person's current mood, exactly how and why this happens remains to be explained. The search for a theory would be aided by answers to a host of novel questions. For instance, what role does affect/environment awareness play in free association, self-judgment, person perception, and other social cognitive tasks that, like autobiographical memory, are known to be highly sensitive to mood effects? Also, is there a theoretically meaningful nexus between the concept of awareness, as it applies to mood congruence, and its applicability to other aspects of social cognition, including the influence of explicit versus implicit attitudes on behavior (Greenwald and Banaji, 1995; Greenwald et al., 2002) and the conscious versus nonconscious priming of stereotypes (Bargh and Chartrand, 1999; Bargh and Ferguson, 2000)? And is affect/environment awareness relevant not only to mood-congruent memory, but to mood-dependent memory as well (Eich and Macaulay, 2006)?

This concludes our brief look at the concept of mood congruence and of some of the ways in which affective states influence cognition in general and memory in particular. Now we turn attention from memory 'in' affect to memory 'about' affect, and take up the complex, challenging, and controversial matter of memory for traumatic events.

## 2.15.2 Memory about Affect

The effects of emotion on memory for personal events is one of the most controversial issues in all contemporary cognition/emotion research. This issue has been studied in different contexts, and in every case the only conclusion upon which everyone agrees is that the impact of emotion on memory is an extremely contentious topic. For example, in research investigating flashbulb memories for salient news events, some have proposed that emotion enhances event recollection (Conway, 1995), whereas others have argued that flashbulb memories are not especially accurate (McCloskey et al., 1988; Neisser and Harsch, 1992). Similarly, in studies involving eyewitness memory, whereas some have claimed that emotion promotes eyewitness performance (Yuille and Cutshall, 1986), others have maintained that emotion impairs eyewitness memory (Loftus and Burns, 1982). While discussion of the role of emotion has been contentious in both the domains of news events and eyewitness memory (for a review, see Schooler and Eich, 2000), in no domain are the paradoxical claims regarding the effects of emotion on memory more evident than in the territory of trauma. The remainder of the chapter will focus on memory for traumatic events.

### 2.15.2.1 The Memory Wars

How people remember and forget trauma has been among the most polarized, controversial debates in the history of psychology and psychiatry (Loftus, 1997; McNally, 2003). Especially bitter has been the controversy regarding the authenticity of reportedly repressed and recovered memories of childhood sexual abuse (CSA). This controversy has sometimes been dubbed the memory wars (Crews, 1995; Schacter, 1995).

Some scholars believe that the mind protects itself by repressing or dissociating traumatic events from awareness, making it difficult for victims to remember their most horrible experiences until many years later. As Brown et al. (1998: 97) have argued, "when emotional material reaches the point of being traumatic in intensity – something that cannot be replicated in artificial laboratories – in a certain subpopulation of individuals, material that is too intense may not be able to be consciously processed and so may become unconscious and amnesic." Conversely, many psychologists hold that abuse, combat, and other overwhelmingly horrifying events are ostensibly imprinted in memory and are seldom, if ever, truly forgotten (Pope et al., 1999; McNally, 2003; Kihlstrom, 2004). For example, Roediger and Bergman (1998: 1095) remarked that it is "mysterious how painful events, banished to an unconscious state for years through mechanisms of dissociation or repression, could be brought back to consciousness and recollected with great fidelity."

Additionally, skeptics have warned that memories may be susceptible to distortions (Schacter, 1999) and that therapeutic interventions such as hypnosis, dream interpretation, and imagination – intended to recover memories of CSA – may unintentionally foster pseudo-memories of CSA (Loftus, 1993; Lindsay and Read, 1994). Thus, McNally (2005: 815) maintained that "the movement to help survivors recall these allegedly repressed memories resulted in the worst catastrophe to befall the mental health field since the lobotomy era."

### 2.15.2.2 Remembering and Forgetting Trauma

Since the onset of the memory wars, a multitude of studies have addressed whether traumatic memories can be forgotten. A number of retrospective and prospective studies of CSA have found a nontrivial proportion of victims saying that they at some point in their life had not remembered their abuse. For example, in one of the most widely cited retrospective studies, Briere and Conte (1993: 24) asked 450 patients in treatment for CSA the following question: "During the period of time between when the first forced sexual experience happened and your eighteenth birthday, was there a time when you could not remember the forced sexual experience?" Fifty-nine percent of the patients answered that there had been such a time. Accordingly, Briere and Conte concluded that a substantial number of survivors experience sexual abuse-related repression of their traumatic memories prior to recovering the memories later in life.

However, due to methodological limitations, this study cannot be taken as support for massive repression. First, participants in the study were patients possibly exposed to therapeutic techniques likely to foster memories of abuse (Poole et al., 1995). Also, as in many studies in this domain, it was not established whether the recalled abuse had actually happened. Moreover, the duration of amnesia for trauma was unspecified. Perhaps the most important issue concerns the question that respondents were given. In a way, this question was formulated in an ambiguous way. Thus, McNally and colleagues pointed out that participants were more likely answering a different question: "Was there ever a time that you did not think about having been abused?" (McNally et al., 2004: 131). That is why an affirmative answer to this question does not necessarily provide solid evidence for the type of massive repression put forward by CSA researchers. Instead, such a positive reaction might simply mean that those who experienced CSA can sometimes manage not to think about the abuse. These and other critical points have also been made with regard to similar retrospective studies published in the last 15 years.

A much smaller number of studies have used a prospective methodology to assess whether traumatic events can be forgotten. In an influential study by Williams (1994), 129 women with previously documented histories of CSA were interviewed. Of these, 38% failed to report the index event of abuse for which Williams had a record. Some authors have interpreted these data as showing that massive forgetting of trauma is not only possible, but even very common. However, there are several other, more likely explanations. A majority of the participants, 68%, who had apparently forgotten the index event of abuse did report other abuse events, suggesting that the index event may have merely been less traumatic or less important to them than other instances of CSA. Given that several women had been abused when they were younger than 5, not remembering the abuse might be the result of childhood amnesia. Moreover, one can argue that the younger the child at the time of the index event, the more likely she is to fail to understand the abuse as sexual at the time. Also, other women may not have wanted to label themselves as abused and/or disclose such personal matters to the interviewer. Thus, a failure to disclose cannot be regarded as evidence of repression (Loftus et al., 1994).

A study by Goodman and colleagues (2003) provides further data on failure to disclose abuse. They assessed 168 persons who had been involved in legal proceedings concerning sexual abuse. These proceedings occurred when the persons were approximately 9 years old. A survey was administered 13 years after the persons had been involved in the legal proceedings. Questions about sexual abuse were inserted in a longer survey concerning legal attitudes and experiences. Results revealed that about 16% failed to report the target incident during a telephone interview conducted approximately 13 years after the events in question. Nondisclosure dropped to 8% after follow-up by a mailed questionnaire and a telephone interview. Moreover, an in-depth analysis by Goodman and Paz-Alonso (2006) yielded a reduced estimate of 4% for the incidence of traumatic amnesia. As these studies indicate, claims of widespread repression and recovery of childhood abuse have been exaggerated. Accordingly, Goodman et al. (2003) concluded that the findings, rather than supporting the existence of special memory mechanisms unique to traumatic events, instead imply that normal cognitive operations underlie long-term memory for CSA.

### 2.15.2.3 False and Recovered Memories

Another possibility for the impression that one has harbored repressed memories is that a failure to remember traumatic events took place because such events did not actually occur in the first place (Loftus, 1998). On first impression, the idea that someone might remember having experienced a trauma that never took place seems an unlikely account for repression. Yet, people have recollected atrocities that never happened and have been experiencing the emotional pain paralleled with their belief in the authenticity of their memories. Some of the improbable traumatic events for which people claim to have recovered memories in recent years involve satanic ritual abuse (Scott, 2001) and abduction by space aliens (Mack, 1994; Clancy, 2005), memories which are occasionally 'recovered' during psychotherapy. In reviewing the influence of psychotherapy, Lindsay and Read (1994: 304) concluded that "there are good reasons to believe that: (1) some recollections produced by intensive memory recovery may be false; and (2) when such techniques are used it is very difficult to discriminate between clients who are remembering accurately and clients who believe they are remembering accurately but are not."

The fact that a growing number of former patients have retracted their claims of CSA also suggests that false CSA memories can be induced by therapists. Most retractor cases involve adults who had sought psychotherapy for depression or related complaints. During therapy, memories of CSA were recovered. However, later patients come to believe that the 'recovered memories' were only products of therapeutic suggestion (e.g., Ost et al., 2002).

In the 1990s, the experimental research community responded in earnest to these frequent memory reports by patients claiming their experiences had been previously repressed. If these memories were not authentic, where could they have come from? If they were false, how could they develop? With these questions in mind, several lines of research on the development of false beliefs and memories began to flourish (for reviews, see Laney and Loftus, 2005; Smeets et al., 2005). One of the best-known tasks that has been strikingly successful in creating pseudo-memories in the laboratory is the Deese-Roediger-McDermott (DRM) paradigm (Deese, 1959; Roediger and McDermott, 1995). In this task, participants often falsely recall and recognize a nonpresented word or critical lure (such as 'sleep') following presentation of several of its strongest associates ('bed, rest, awake, tired,' and the like).

The DRM paradigm relies on semantic material. Yet, apart from semantic material, research has demonstrated that techniques such as imagination inflation (Garry et al., 1996), dream interpretation (Mazzoni et al., 1999), and suggestions containing incorrect feedback (Crombag et al., 1996; Hyman and Billings, 1998; Jelicic et al., 2006) may create false beliefs and pseudo-memories. Moreover, recent studies have successfully employed doctored photographs (e.g., a youngster riding in a hot-air balloon) to suggest childhood events that never happened to the child or adult participants (Wade et al., 2002). Additionally, studies have shown that experimental manipulations intended to implant pseudo-memories may have overt behavioral consequences (Bernstein et al., 2005).

### 2.15.2.4 Recovered Memories in the Laboratory

Remarkably, until recently no studies had been conducted on the cognitive functioning of people in the center of this recovered-memory debate: those who report repressed and recovered CSA memories. This state of affairs could be due to the fact that few clinicians have expertise in laboratory research and few cognitive psychologists have access to trauma populations (McNally et al., 2004). In fact, Richard McNally and Susan Clancy of Harvard University were the first to apply experimental methods to investigate memory functioning in people reporting repressed and recovered memories of CSA. By doing so, their studies have tested hypotheses relevant to mechanisms implicated in the ability to repress and recover traumatic memories, as well as mechanisms relevant to forming pseudo-memories of trauma (McNally, 2003). For example, they examined whether individuals reporting recovered CSA memories are more prone to false memory effects induced in the laboratory (Clancy et al., 2000). In one of their studies, they used the previously described DRM paradigm to show that, relative to individuals with continuous memories and controls with no history of abuse, individuals reporting recovered CSA memories more often falsely recognized the nonpresented critical lures. Subsequently, these findings were extended to trauma-related material (Geraerts et al., 2005). That is, besides neutral DRM lists (e.g., critical lure 'sleep'), trauma-related lists (e.g., critical lure 'assault') were employed. It was found that individuals reporting recovered abuse memories are more prone to falsely recalling and recognizing neutral and trauma-related words that were never presented.

Several researchers have argued that such susceptibility to false memories may be due to a source-monitoring deficit, that is, incorrect judgments about the origin or source of information (Johnson et al., 1993). For example, subjects may think of the nonpresented lure at study, so then at test they must differentiate between memories of internally generated thoughts versus memories of the studied words. Results reported by Clancy et al. (2000) and by Geraerts et al. (2005) suggest that individuals reporting recovered CSA memories may have a source-monitoring deficit for all types of material, whether the content is neutral or trauma-related. It can be speculated that these individuals have a tendency to adopt an internally generated thought as being a genuine memory. This could have important implications, both in terms of the development of false memories *per se* and in terms of the development of mistaken beliefs. Thus it may be that a subsample of those with recovered memories developed false memories via a subtle interaction between intrinsic source-monitoring difficulties and suggestive therapeutic techniques.

### 2.15.2.5 Underestimation of Prior Remembering

Although the research above suggests that recovered memories are likely to be false memories, Schooler and coworkers (e.g., Schooler et al., 1997; Shobe and Schooler, 2001) described several case studies of individuals who experienced the discovery of apparently long-forgotten memories of abuse, memories for which corroborative information could be found. Interestingly, in two of the cases the partners of the women who reported full-blown recovered-memory experiences said that the women had talked about the abuse before they had the recovered-memory experience. In both cases, the women seemed to be surprised to discover that they had talked about the abuse prior to their recovered-memory experiences. Schooler and colleagues proposed that these cases illustrate a forgot-it-all-along (FIA) phenomenon, which at its core entails the underestimation of prior recollections of past events.

Recent studies have provided elegant laboratory analogs of this FIA phenomenon. For example, a series of experiments by Arnold and Lindsay (2002, 2005) required participants to recall material in qualitatively similar versus different ways on two occasions. They argued that if the retrieval of CSA memories in qualitatively different ways can lead to the underestimation of previous CSA recollections, then this mechanism should transfer into the lab. In the basic procedure, participants studied a list of homographic target words, each accompanied by a biasing context word (e.g., hand: PALM). In Test 1, participants were tested on a subset of the study list, with some of the target items being cued with the studied-context word (e.g., hand: P–M) and the rest of the items cued with another-context word (e.g., tree: P–M). In the final test, participants were tested on all of the studied items, and the studied-context cues were always given as recall prompts. Additionally, after recalling each word, participants were required to judge whether they had recalled that word on Test 1. The key result was that participants more often forgot their prior recall of the words when they had been cued with the other-context cue than with the studied-context cue on Test 1. Hence, these results provided compelling evidence that remembering a past event in a different way can result in a failure to remember a prior instance of recalling that event.

Recently, the link between the FIA effect and recovered memories has been studied in the laboratory by Geraerts et al. (2006). The issue of interest was whether individuals reporting recovered CSA memories are more prone to underestimating their prior remembering, relative to individuals with continuous CSA memories and controls reporting no history of abuse. Using Arnold and Lindsay's (2002) FIA test, Geraerts et al. (2006) found that participants with recovered CSA memories were found to be more prone to forget that they had previously recalled a studied item when they had been cued to think of it differently on two recall tests. That is, the FIA effect was larger in those who reported recovered memories.

In a related study, Geraerts et al. (2006) asked participants to recall autobiographical events (e.g., being home alone as a child) in an emotionally negative or positive framing across three test sessions over a period of 4 months. Given the cue 'being home alone as a child,' for example, a participant assigned a positive framing for that event might recall enjoying the feeling of freedom of having the house to himself/herself; the same participant assigned a negative framing for that event in session 2 might reminisce about feeling lonely after a while.

In the first session, participants were instructed to recall 25 selected events in either a positive or negative frame. After 2 months, participants were asked to recall 16 of the target events a second time. For half of the trials, the framing cue presented with the events corresponded to the negative/positive framing cue presented with the autobiographical events during the first session, whereas for the remaining trials the framing was the opposite from the framing cue presented in the first session (i.e., positive framing if the framing on the first session had been negative, and vice versa). In session 3, again 2 months later, participants were tested on all the target events, accompanied by the framing cues that were presented with the targets during session 1. Again, individuals reporting recovered CSA memories showed an enhanced FIA effect relative to individuals with continuous abuse memories and controls, even when mildly emotional autobiographical material was used over a period of 4 months, conditions that more closely mirror everyday life (if not memories of trauma). These findings imply that some of the participants' recovered CSA memories may be fundamentally accurate, but that these individuals may have underestimated their prior memories for the abuse.

### 2.15.2.6 Discovered or False Memories?

The two basic findings discussed above – source monitoring deficits and the FIA effect – suggest radically different interpretations of recovered memories. On the one hand, studies by Clancy et al. (2000) and Geraerts et al. (2005) show that reports of recovered memories are associated with false memory effects as measured by the DRM task. Conversely, the results reported by Geraerts et al. (2006) indicate that recovered memory reports are intimately related to underestimation of prior remembering. However, it seems implausible that one and the same report of a recovered memory could be linked both to false memory effects and to the underestimation of prior remembering. How can these phenomena be integrated? Careful inspection of the precise types of recovered memory experiences may provide an answer to this question.

Two clearly distinguishable types of recovered memory experiences have been documented in the literature (e.g., Shobe and Schooler, 2001). In one type, people come to believe that they are abuse survivors, commonly attributing their current life difficulties to their repressed memories of abuse. Here, abuse events tend to be recalled gradually over time, often by suggestions of a therapist. People usually indicate that they have 'learned' (e.g., through hypnosis) that the abuse occurred to them. In the other type of recovered memory experience, people are suddenly reminded of events they believe they had not thought about for many years. They are shocked and surprised by their recollection, but not by the content of the memory as such. This kind of recollection differs from the one in which the person is gradually recalling the abuse, often in the course of therapy. For this reason, Schooler and coworkers (Schooler et al., 1997; Schooler, 2001) referred to these suddenly recovered memories as discovered memories, reflecting situations "in which individuals sincerely perceive themselves to have discovered memories of experiences of which they think they had previously been unaware" (Shobe and Schooler, 2001: 100). This term keeps open the possibility that individuals could have discovery experiences corresponding to memories that were not completely forgotten.

Given these two types of recovered-memory experiences, it is not too farfetched to speculate that people who report CSA memories recovered during therapy may score high on tasks yielding false memory effects, like the DRM task. Yet, they may perform similarly to control participants on tasks tapping the FIA effect. Conversely, one would expect that people with spontaneously recovered memories would be especially prone to the FIA effect, whereas they would score similarly to controls on false memory tasks, such as the DRM. Preliminary analyses of the data collected in several studies with individuals reporting recovered CSA memories indicate that this is the case (Geraerts, 2006).

### 2.15.2.7 Corroborative Evidence of Abuse

Recent research supports the view that CSA memories discovered outside of therapy are more likely to reflect genuine events relative to memories recovered in therapy (Geraerts et al., 2007b). In this study, people with recovered CSA memories responded to an extensive memory questionnaire. Participants were asked to characterize their prior degree of forgetting, the quality of their memory recovery if they had one, the nature and context of the abuse, and the qualities of their current memory. Moreover, information was sought to verify or corroborate the CSA memories. Memories were characterized as corroborated if one or more of the following three criteria were met: (a) another individual reported learning about the abuse soon (i.e., within the next week) after it occurred, (b) another individual reported having also been abused by the alleged perpetrator, or (c) another individual reported having committed the abuse him/herself. The presence of corroborative evidence was evaluated by two raters blind to any additional information associated with each case.

Results revealed that memories recovered unexpectedly, outside of therapy, were significantly more verifiable than memories that were reported to have been gradually recovered within the context of therapy. As indicated in **Table 1**, abuse events recovered during therapy could not be verified, while 37% of the CSA memories discovered outside of therapy were independently corroborated; the latter figure is similar to the 45% verification rate found for continuously accessible memories. These results support the view that memories recovered unexpectedly outside of therapy (i.e., discovered memories) are more likely to correspond to genuine abuse events, relative to memories recovered in therapy.

**Table 1** Percentage of memories of childhood sexual abuse that could or could not be corroborated

| | *Corroboration* | |
|---|---|---|
| *Participant group* | *Yes* | *No* |
| Continuous recollection | 45% (32) | 55% (39) |
| Recovered out of therapy | 37% (15) | 63% (26) |
| Recovered in therapy | 0% (0) | 100% (16) |

Number of participants per condition is enclosed in parentheses.
Source: Geraerts E, Schooler JW, Merckelbach H, Jelicic M, Hauer BJA, and Ambadar Z (2007b) The reality of recovered memories: Corroborating continuous and discontinuous memories of childhood sexual abuse. *Psychol. Sci.* 18: 564–568; used with permission from Blackwell Publishing.

Moreover, in this study, 85% of participants reporting recovered memories failed to appreciate their abuse as traumatic at the time it occurred, in part due to lack of understanding the nature of the event (for related results, see Clancy and McNally, in press). In fact, many of them rated the abuse as being more traumatic now than it was at the time of the abuse. This was especially the case for participants who suddenly recalled long forgotten and often corroborated episodes of abuse. Several of them were exposed to one or sometimes more episodes of abuse that were nonpenetrative (e.g., fondling). Such events were experienced as confusing or distressing but not essentially frightening. Individuals reporting them might have managed not to think about these experiences, particularly if retrieval cues were absent (e.g., in cases in which the victim or the perpetrator had moved away). Years later, appropriate retrieval cues might be encountered, triggering the recollection of the long-forgotten abuse experiences, which the person now correctly understands to be sexual abuse. This realization often is accompanied by an onrush of emotions which is interpreted as the impact of remembering something for the first time.

Although such cases undoubtedly qualify as recovered/discovered memories of sexual abuse, they cannot be taken as evidence for amnesia. Contrary to the standard view of repression, people do not forget their abuse in the strict sense of the word, because the abuse was neither perceived as traumatic nor recognized as abuse. No special mechanisms, such as repression or dissociation, have to be put forward to clarify why these misapprehended abuse experiences did not come to mind for many years. Also, no special mechanisms such as repression are needed to explain reports of CSA memories recovered during therapy. Memories recovered during therapy, as well as discovered memories, both render a scenario in which a false impression of previous nonavailability of abuse memories arises, while in fact, no special mechanisms such as dissociation or repression are needed to account for these impressions of repression.

#### 2.15.2.8 Mechanisms of Traumatic Memory

Does traumatic memory involve special mechanisms? According to one popular view known as the trauma-memory argument, memories of traumatic events have special properties that distinguish them from ordinary memories (for a critical discussion, see Kihlstrom, 1996). In this view, traumatic memories are qualitatively different (i.e., processed and stored differently) from other types of memories, thereby involving mechanisms different from those associated with general memory functioning (van der Kolk, 1996). This view asserts that many survivors of a trauma invoke mechanisms such as repression and dissociation, which result in dissociative amnesia for the stressful event itself. Moreover, it is contended that survivors of a trauma suffer from intrusions with strong sensory qualities. This dissociative style of processing would also create a substantial overlap between dissociative and posttraumatic stress disorder symptoms. There are several versions of this theoretical stance (Brewin et al., 1996; Ehlers and Clark, 2000), but the core assumption they have in common is that trauma has a special impact on the way in which memories of the traumatic event are organized (for discussions, see Kihlstrom, 1996; Shobe and Kihlstrom, 1997; Kihlstrom, 2006; for a reply, see Nadel and Jacobs, 1998).

Although the trauma-memory argument has gained popularity among many clinicians, some findings argue against this view. Systematic studies suggest that only a small minority of war victims report dissociative amnesia. For example, Kuch and Cox (1992) studied 124 Holocaust survivors and found that dissociative amnesia, with an estimated lifetime prevalence rate of 3%, was quite rare in this group. Likewise, Merckelbach and colleagues (Merckelbach et al., 2003) found in a group of 29 Dutch concentration camp survivors only one survivor reporting mnemonic experiences that might be taken as evidence for dissociative amnesia. The authors noted that in this case there was a serious possibility that drug abuse contributed to the poor memory of the traumatic episode. Similarly, Geraerts and colleagues (Geraerts et al., 2007a) found that in a sample of Croatian war veterans who had been confronted with extremely aversive events during the Balkan wars, dissociative amnesia was rarely reported. In sum, several recent findings do not support the existence of special memory mechanisms that are unique to traumatic events.

## 2.15.3 Integrating Memory in and about Affect

In the preceding pages, we have treated memory in and about affect as distinct topics. Such a treatment was possible because research on mood-congruent cognition has had relatively little overlap with research on memory for traumatic events. Nevertheless, consideration of these topics together invites exploration of the possible empirical and theoretical issues that might unite them. To this end, we close with a discussion of potential ways in which the principles and findings of mood congruence might apply to understanding the processes leading to reports of recovered memories of trauma.

### 2.15.3.1 Connections between Mood Congruence and Traumatic Memory

According to the AIM, the motivational and resource demands of the situation determine which of two distinct processes – affect priming or AAI – mediate mood-congruent effects. Given the variable conditions under which individuals can think about traumatic experiences, it seems likely that each of these processes might influence recovered memory reports under different circumstances.

#### *2.15.3.1.1 Affect priming*

When individuals are highly motivated, have sufficient resources, and are elaborating on self-relevant information, they are likely to experience affective infusion, whereby the information that is generated/attended to is shaped in accordance with the present mood, presumably through a process of affect priming. When individuals are in therapy they are talking about issues of immense self-relevance. They experience powerful emotions. They are highly motivated to think through their experiences. And with the therapists' support, they are likely to have adequate resources to engage in elaborative systematic processing. Thus therapy potentially provides an extremely fertile ground for the priming of affect-related memories, thoughts, perceptions, and other cognitive constructions. From this perspective, it seems possible that affect priming, when combined with a therapist's suggestions, could spawn false memories. For example, if therapy invokes emotions of betrayal and trauma, then affective infusion might facilitate the adoption of suggested memories that are consistent with those emotions.

Admittedly, negative emotional states can minimize susceptibility to suggestion, whereas the above characterization proposes that therapy-induced negative emotions might enhance suggestibility. Importantly, however, the reduced susceptibility to misinformation reviewed in this chapter involved minor details of little self-relevance, and not in accord with the induced negative affect participants were experiencing. In contrast, therapy-suggested experiences of abuse would be highly self-relevant and likely in accord with the emotional state that the patient is experiencing at the time. Thus, in the context of therapy, the capacity for affect priming to generate affectively matched cognitions may outweigh the capacity for negative emotions to reduce suggestibility, thereby leading to a net increase in false memories.

Though speculative, the suggestion that affect priming could be a source of therapy-induced false memories might be empirically explored by examining whether the match between an affective state and a memory suggestion affects the generation of false memories. For example, in the imagination inflation paradigm (Garry et al., 1996), imagining events, such as putting one's hand through a window or finding a 10-dollar bill, increases the perceived likelihood that these events occurred. If affect priming enhances false memories in therapy, then it seems likely that imagination inflation might similarly be associated with affect-infusion (or mood-congruent) effects. Accordingly, participants may be more likely to believe they had once found a 10-dollar bill if they imagine this in a good mood, or more likely to believe they put their hand through a window, if they imagine this in a bad mood. Such a findings would suggest that affect priming could be an even greater source of false memories in the substantially more emotional and self-relevant context of therapy.

#### *2.15.3.1.2 Affect-as-information*

In the secure atmosphere of therapy, individuals are likely to have the resources to think about traumatic experiences using elaborative systematic processing. However, when memories of abuse arise unbidden and out of therapy, the emotional onrush can be overwhelming. Individuals reporting memory discoveries outside of therapy describe their experience with terms such as stunned, chaos in my emotions, overwhelmed, and like a ton of bricks just hit me (Schooler, 2001).

According to the AIM, in a situation in which cognitive resources are overwhelmed by emotion, it is likely that AAI processes would take place. In keeping with this view, Schooler (2001) speculated that AAI may lead individuals to infer, based on their profound affective experience of discovery, that they must be remembering the abuse for the first time. According to this discovery misattribution account, individuals confuse the emotion associated with discovering a new interpretation of the experience with that of discovering the memory itself.

Several strands of evidence support a discovery misattribution account whereby individuals use the affect associated with discovering a new understanding of their experience to falsely infer that they have discovered a forgotten memory. First, both of the original cases of misconstrued forgetting involved individuals who reported experiencing an overwhelming onrush of emotion after reinterpreting their abuse experiences (Schooler, 2001). For example, one case involved a woman who reported having been raped while hitchhiking. In her recounting of her memory, she reported that originally she had thought of the experience as a sexual experience gone awry, indicating that she had "made such a mess of it . . . by resisting what I thought was supposed to be a sexual experience" (Schooler, 2001: 120). However, following the onrush of emotions associated with her memory discovery, she reported thinking "my God . . . I had been raped! . . . that's a crime! I was 16, just a kid" (Schooler, 2001: 121). Similarly, in the large-scale corroborative effort by Geraerts et al. (2006), change in interpretation was one of the best predictors of memories being characterized as previously forgotten.

Laboratory research also provides evidence for discovery misattribution. For example, the experience of discovering the solution to an anagram can be confused with the experience of remembering having seen the word corresponding to the anagram's solution (S. Dougal and J. W. Schooler, unpublished observations). Together these strands of evidence suggest that the reduced resources associated with the emotional onrush of realizing that one was the victim of abuse, could enable an AAI process whereby individuals misattribute the emotion of discovering a new understanding of the event to that of discovering the memory itself.

### 2.15.3.2 Final Thought

Memory research has come a long way since the time that it shunned emotion. Our review of the role of emotion in and about memory reveals that there is much that simply could not have been known about memory, were memory researchers to have remained limited to the random-word-list paradigms that were the bread-and-butter of memory experiments for so many years. Not only did such paradigms lack the emotional manipulations that have proven to be so informative, but by ignoring elaboration and self-relevance, these procedures were inherently insensitive to many of the consequences of affect. Moreover, understanding memory for emotional events necessarily requires researchers to leave the confines of their laboratories and explore the far more complex situations in which traumatic memories actually take place.

Nevertheless, consideration of the relations between traumatic-memory reports and performance on basic word-list paradigms has yielded critical insights into the processes underlying the formation of recovered-memory reports. Thus, while memory in and about affect illustrates just how far memory research has come, its also illuminates the value of remembering its roots.

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## References

Arnold MM and Lindsay DS (2002) Remembering remembering. *J. Exp. Psychol. Learning, Mem. Cogn.* 28: 521–529.
Arnold MM and Lindsay DS (2005) Remembrance of remembrance past. *Memory* 13: 533–549.
Bargh JA and Chartrand TL (1999) The unbearable automaticity of being. *Am. Psychol.* 54: 462–479.
Bargh JA and Ferguson ML (2000) Beyond behaviorism: On the automaticity of higher mental processes. *Psychol. Bull.* 126: 925–945.
Berkowitz L, Jaffee S, Jo E, and Troccoli BT (2000) On the correction of feeling-induced judgmental biases. In: Forgas JP (ed.) *Feeling and Thinking: The Role of Affect in Social Cognition*, pp. 131–152. New York: Cambridge University Press.
Bernstein DM, Laney C, Morris EK, and Loftus EF (2005) False beliefs about fattening foods can have healthy consequences. *Proc. Natl. Acad. Sci. USA* 102: 13724–13731.
Blaney PH (1986) Affect and memory: A review. *Psychol. Bull* 99: 229–246.
Bless H (2000) The interplay of affect and cognition: The mediating role of general knowledge structures. In: Forgas JP (ed.) *Feeling and Thinking: The Role of Affect in Social Cognition*, pp. 201–222. New York: Cambridge University Press.
Bless H and Fiedler K (2006) Mood and the regulation of information processing and behavior. In: Forgas JP (ed.) *Affect in Social Thinking and Behavior*, pp. 65–84. New York: Psychology Press.
Bower GH (1981) Mood and memory. *Am. Psychol.* 36: 129–148.
Bower GH (1983) Affect and cognition. *Philos. Trans. R. Soc. Lond. B* 302: 387–402.
Bower GH (1987) Commentary on mood and memory. *Behav. Res. Ther.* 25: 443–455.
Bower GH (1991) Mood congruity of social judgments. In: Forgas JP (ed.) *Emotion and Social Judgments*, pp. 31–53. Oxford: Pergamon.
Bower GH (1992) How might emotions affect learning? In: Christianson S-A (ed.) *Handbook of Emotion and Memory*, pp. 3–31. Hillsdale, NJ: Erlbaum.
Bower GH and Cohen PR (1982) Emotional influences in memory and thinking: Data and theory. In: Clark MS and Fiske ST (eds.) *Affect and Cognition*, pp. 291–331. Hillsdale, NJ: Erlbaum.
Bower GH and Forgas JP (2000) Affect, memory, and social cognition. In: Eich E, Kihlstrom JF, Bower GH, Forgas JP, and Niedenthal PM (eds.) *Cognition and Emotion*, pp. 87–168. New York: Oxford University Press.
Bower GH and Mayer JD (1985) Failure to replicate mood-dependent retrieval. *Bull. Psychon. Soc.* 23: 39–42.
Bradley PP and Mathews AM (1983) Negative self schemata in clinical depression. *Br. J. Clin. Psychol.* 22: 173–181.
Brewin CR, Dalgleish T, and Joseph S (1996) A dual representation theory of posttraumatic stress disorder. *Psychol. Rev.* 103: 670–686.
Briere J and Conte JR (1993) Self-reported amnesia for abuse in adults molested as children. *J. Trauma. Stress* 6: 21–31.
Brown D, Scheflin AW, and Hammond DC (1998) *Memory, Trauma Treatment, and the Law*. New York: Norton.

Brown JD and Mankowski TA (1993) Self-esteem, mood, and self-evaluation: Changes in mood and the way you see you. *J. Pers. Soc. Psychol.* 64: 421–430.
Burke M and Mathews AM (1992) Autobiographical memory and clinical anxiety. *Cogn. Emot.* 6: 23–35.
Byrne D and Clore GL (1970) A reinforcement model of evaluation responses. *Personality* 1: 103–128.
Ciarrochi JV and Forgas JP (1999) On being tense yet tolerant: The paradoxical effects of trait anxiety and aversive mood on intergroup judgments. *Group Dyn. Theory Res. Pract.* 3: 227–238.
Ciarrochi JV and Forgas JP (2000) The pleasure of possessions: Affect and consumer judgments. *Eur. J. Soc. Psychol.* 30: 631–649.
Clancy SA (2005) *Abducted: How People Come to Believe They Were Kidnapped by Aliens*. Cambridge; MA: Harvard University Press.
Clancy SA and McNally RJ (in press) Who needs repression? Normal memory processes can explain forgetting of childhood sexual abuse. *Sci. Rev. Mental Health Pract.*
Clancy SA, Schacter DL, McNally RJ, and Pitman RK (2000) False recognition in women reporting recovered memories of sexual abuse. *Psychol. Sci.* 11: 26–31.
Clark MS and Isen AM (1982) Towards understanding the relationship between feeling states and social behavior. In: Hastorf AH and Isen AM (eds.) *Cognitive Social Psychology*, pp. 73–108. New York: Elsevier.
Clark MS and Waddell BA (1983) Effects of moods on thoughts about helping, attraction and information acquisition. *Soc. Psychol. Q.* 46: 31–35.
Clore GL and Byrne D (1974) The reinforcement affect model of attraction. In: Huston TL (ed.) *Foundations of Interpersonal Attraction*, pp. 143–170. New York: Academic Press.
Clore GL, Gasper K, and Garvin E (2001) Affect as information. In: Forgas JP (ed.) *Handbook of Affect and Social Cognition*, pp. 121–144. Mahwah, NJ: Erlbaum.
Coan JA and Allen JB (eds.) (2007) *The Handbook of Emotion Elicitation and Assessment*. New York: Oxford University Press.
Conway MA (1995) *Flashbulb Memories*. Hillsdale, NJ: Erlbaum.
Crews F (1995) *The Memory Wars: Freud's Legacy in Dispute*. New York: New York Review of Books.
Crombag HFM, Wagenaar WA, and van Koppen PJ (1996) Crashing memories and the problem of ''source monitoring.'' *Appl. Cogn. Psychol.* 10: 95–104.
Deese J (1959) On the prediction of occurrence of particular verbal intrusions in immediate recall. *J. Exp. Psychol.* 58: 17–22.
Ehlers A and Clark DM (2000) A cognitive model of posttraumatic stress disorder. *Behav. Res. Ther.* 38: 319–345.
Eich E (1995) Mood as a mediator of place dependent memory. *J. Exp. Psychol. Gen.* 124: 293–308.
Eich E (2007) Mood, memory, and the concept of context. In: Roediger HL, Dudai Y, and Fitzpatrick SM (eds.) *Science of Memory: Concepts*, pp. 107–110. New York: Oxford University Press.
Eich E and Macaulay D (2006) Cognitive and clinical perspectives on mood-dependent memory. In: Forgas JP (ed.) *Affect in Social Thinking and Behavior*, pp. 105–121. New York: Psychology Press.
Ellis HC and Ashbrook PW (1988) Resource allocation model of the effects of depressed mood states on memory. In: Fiedler K and Forgas JP (eds.) *Affect, Cognition and Social Behavior*, pp. 25–43. Toronto: Hogrefe.
Ellis HC and Moore BA (1999) Mood and memory. In: Dalgleish T and Power M (eds.) *Handbook of Cognition and Emotion*, pp. 193–210. Chichester, UK: Wiley.
Eysenck MW, MacLeod C, and Mathews AM (1987) Cognitive functioning in anxiety. *Psychol. Res.* 49: 189–195.
Feshbach S and Singer RD (1957) The effects of fear arousal and suppression of fear upon social perception. *J. Abnorm. Soc. Psychol.* 55: 283–288.
Fiedler K (1990) Mood-dependent selectivity in social cognition. In: Stroebe W and Hewstone M (eds.) *European Review of Social Psychology,* vol. 1, pp. 1–32. New York: Wiley.
Fiedler K (1991) On the task, the measures and the mood in research on affect and social cognition. In: Forgas JP (ed.) *Emotion and Social Judgments*, pp. 83–104. Oxford: Pergamon.
Fiedler K (2000) Towards an integrative account of affect and cognition phenomena using the BIAS computer algorithm. In: Forgas JP (ed.) *Feeling and Thinking: The Role of Affect in Social Cognition*, pp. 223–252. New York: Cambridge University Press.
Fiedler K (2001) Affective influences on social information processing. In: Forgas JP (ed.) *Handbook of Affect and Social Cognition*, pp. 163–185. Mahwah, NJ: Erlbaum.
Forgas JP (1992) On bad mood and peculiar people: Affect and person typicality in impression formation. *J. Pers. Soc. Psychol.* 62: 863–875.
Forgas JP (1993) On making sense of odd couples: Mood effects on the perception of mismatched relationships. *Pers. Soc. Psychol. Bull.* 19: 59–71.
Forgas JP (1995) Mood and judgment: The affect infusion model (AIM). *Psychol. Bull.* 117: 39–66.
Forgas JP (2002) Towards understanding the role of affect in social thinking and behavior. *Psychol. Inq.* 13: 90–102.
Forgas JP and Ciarrochi JV (2002) On managing moods: Evidence for the role of homeostatic cognitive strategies in affect regulation. *Pers. Soc. Psychol. Bull.* 28: 336–345.
Forgas JP and Moylan SJ (1987) After the movies: The effects of transient mood states on social judgments. *Pers. Soc. Psychol. Bull.* 13: 478–489.
Forgas JP, Bower GH, and Moylan SJ (1990) Praise or blame? Affective influences on attributions for achievement. *J. Pers. Soc. Psychol.* 59: 809–818.
Forgas JP, Vargas P, and Laham S (2005) Mood effects on eyewitness memory: Affective influences on susceptibility to misinformation. *J. Exp. Soc. Psychol.* 41: 574–588.
Forgas JP, Haselton M, and von Hippel W (eds.) (2007) *Evolutionary Psychology and Social Cognition*. New York: Psychology Press.
Frijda N (1986) *The Emotions*. Cambridge: University Press.
Garry M, Manning CG, Loftus EF, and Sherman SJ (1996) Imagination inflation: Imagining a childhood event inflates confidence that it occurred. *Psychon. Bull. Rev.* 3: 208–214.
Geraerts E (2006) *Remembrance of Things Past: The Cognitive Psychology of Remembering and Forgetting Trauma.* PhD Thesis, Maastricht University, The Netherlands.
Geraerts E, Smeets E, Jelicic M, van Heerden J, and Merckelbach H (2005) Fantasy proneness, but not self-reported trauma is related to DRM performance of women reporting recovered memories of childhood sexual abuse. *Conscious. Cogn.* 14: 602–612.
Geraerts E, Arnold MM, Lindsay DS, Merckelbach H, Jelicic M, and Hauer B (2006) Forgetting of prior remembering in people reporting recovered memories of childhood sexual abuse. *Psychol. Sci.* 17: 1002–1008.
Geraerts E, Kozarić-Kovačić D, Merckelbach H, Peraica T, Jelicic M, and Candel I (2007a) Traumatic memories in war veterans: Not so special after all. *Conscious. Cogn.* 16: 170–177.
Geraerts E, Schooler JW, Merckelbach H, Jelicic M, Hauer BJA, and Ambadar Z (2007b) The reality of recovered memories: Corroborating continuous and discontinuous memories of childhood sexual abuse. *Psychol. Sci.* 18: 564–568.

Goodman GS and Paz-Alonso PM (2006) Trauma and memory: Normal versus special memory mechanisms. In: Uttl B, Ohta N, and Siegenthaler AL (eds.) *Memory and Emotions: Interdisciplinary Perspectives*. New York: Blackwell.
Goodman GS, Ghetti S, Quas JA, et al. (2003) A prospective study of memory for child sexual abuse: New findings relevant to the repressed-memory controversy. *Psychol. Sci.* 14: 113–118.
Greenwald AG and Banaji MR (1995) Implicit social cognition: Attitudes, self-esteem, and stereotypes. *Psychol. Rev.* 102: 4–27.
Greenwald AG, Banaji MR, Rudman LA, Farnham SD, Nosek BA, and Mellot DS (2002) A unified theory of implicit attitudes, stereotypes, self-esteem, and self-concept. *Psychol. Rev.* 109: 3–25.
Haselton MG and Ketelaar T (2006) Irrational emotions or emotional wisdom? The evolutionary psychology of affect and social behavior. In: Forgas JP (ed.) *Affect in Social Thinking and Behavior*, pp. 21–40. New York: Psychology Press.
Heider F (1958) *The Psychology of Interpersonal Relations*. New York: Wiley.
Hyman IEJ and Billings FJ (1998) Individual differences and the creation of false childhood memories. *Memory* 6: 1–20.
Ingram RE (1989) External validity issues in mood and memory research. *J. Soc. Behav. Pers.* 4: 57–62.
Isen AM (1984) Toward understanding the role of affect in cognition. In: Wyer RS and Srull TK (eds.) *Handbook of Social Cognition,* vol. 3, pp. 179–230. Hillsdale, NJ: Erlbaum.
Isen AM (2004) Some perspectives on positive feelings and emotions: Positive affect facilitates thinking and problem solving. In: Manstead ASR, Frijda N, and Fischer A (eds.) *Feelings and Emotions: The Amsterdam Symposium*, pp. 263–281. New York: Cambridge University Press.
Jelicic M, Smeets T, Peters M, Candel I, Horselenberg R, and Merckelbach H (2006) Assassination of a controversial politician: Remembering details from a nonexistent film. *Appl. Cogn. Psychol.* 20: 591–596.
Johnson MK, Hashtroudi S, and Lindsay DS (1993) Source monitoring. *Psychol. Bull.* 114: 3–28.
Kensinger EA and Corkin S (2004) Two routes to emotional memory: Distinct processes for valence and arousal. *Proc. Natl. Acad. Sci. USA* 101: 3310–3315.
Kensinger EA and Schacter DL (2006) Processing emotional pictures and words: Effects of valence and arousal. *Cogn. Affect. Behav. Neurosci.* 6: 110–126.
Kihlstrom JF (1996) The trauma-memory argument and recovered memory therapy. In: Pezdek K and Banks WP (eds.) *The Recovered Memory/False Memory Debate*, pp. 297–311. San Diego: Academic Press.
Kihlstrom JF (2004) An unbalanced balancing act: Blocked, recovered, and false memories in the laboratory and clinic. *Clin. Psychol. Sci. Pract.* 11: 34–41.
Kihlstrom JF (2006) Trauma and memory revisited. In: Uttl B, Ohta N, and Siegenthaler AL (eds.) *Memory and Emotions: Interdisciplinary Perspectives*, pp. 259–291. New York: Blackwell.
Kuch K and Cox BJ (1992) Symptoms of PTSD in 124 survivors of the Holocaust. *Am. J. Psychiatry* 149: 337–340.
LaBar KS and Cabeza R (2006) Cognitive neuroscience of emotional memory. *Nat. Rev. Neurosci.* 7: 54–64.
Laney C and Loftus EF (2005) Traumatic memories are not necessarily accurate memories. *Can. J. Psychiatry* 50: 823–828.
LeDoux JE (1996) *The Emotional Brain*. New York: Simon and Schuster.
Lewinsohn PM and Rosenbaum M (1987) Recall of parental behavior by acute depressives, remitted depressives, and nondepressives. *J. Pers. Soc. Psychol.* 52: 611–619.
Lindsay DS and Read JD (1994) Psychotherapy and memories of child sexual abuse: A cognitive perspective. *Appl. Cogn. Psychol.* 8: 281–338.
Loftus EF (1993) The reality of repressed memories. *Am. Psychol.* 48: 518–537.
Loftus EF (1997) Dispatch from the (un)civil memory wars. In: Read JD and Lindsay DS (eds.) *Recollections of Trauma: Scientific Evidence and Clinical Practice*, pp. 171–198. New York: Plenum.
Loftus EF and Burns TE (1982) Mental shock can produce retrograde amnesia. *Mem. Cognit.* 10: 318–323.
Loftus EF, Garry M, and Feldman M (1994) Forgetting sexual trauma: What does it mean when 38% forget? *J. Consult. Clin. Psychol.* 62: 1177–1181.
Loftus EF, Joslyn S, and Polage D (1998) Repression: A mistaken impression? *Dev. Psychopathol.* 10: 781–792.
Mack JE (1994) *Abduction: Human Encounters with Aliens*, rev. edn. New York: Ballantine.
Mackie D and Worth L (1991) Feeling good, but not thinking straight: The impact of positive mood on persuasion. In: Forgas JP (ed.) *Emotion and Social Judgments*, pp. 201–220. Oxford: Pergamon.
Mathews AM and MacLeod C (1994) Cognitive approaches to emotion and emotional disorders. *Annu. Rev. Psychol.* 45: 25–50.
Mayer JD, Gaschke YN, Braverman DL, and Evans TW (1992) Mood-congruent judgment is a general effect. *J. Pers. Soc. Psychol.* 63: 119–132.
Mazzoni GAL, Loftus EF, Seitz A, and Lynn SJ (1999) Changing beliefs and memories through dream interpretation. *Appl. Cogn. Psychol.* 13: 125–144.
McCloskey M, Wible CG, and Cohen NJ (1988) Is there a special flashbulb-memory mechanism? *J. Exp. Psychol. Gen.* 117: 171–181.
McNally RJ (2003) *Remembering Trauma*. Cambridge, MA: Belknap Press/Harvard University Press.
McNally RJ (2005) Troubles in traumatology. *Can. J. Psychiatry* 50: 815–816.
McNally RJ, Clancy SA, and Barrett HM (2004) Forgetting trauma? In: Reisberg D and Hertel P (eds.) *Memory and Emotion*, pp. 129–154. Oxford: Oxford University Press.
Merckelbach H, Dekkers T, Wessel I, and Roefs A (2003) Amnesia, flashbacks, nightmares, and dissociation in aging concentration camp survivors. *Behav. Res. Ther.* 41: 351–360.
Nadel L and Jacobs WJ (1998) Traumatic memory is special. *Curr. Dir. Psychol. Sci.* 7: 154–156.
Neisser U and Harsch N (1992) Phantom flashbulbs: False recollections of hearing the news about Challenger. In: Winograd E and Neisser U (eds.) *Affect and Accuracy in Recall: Studies of ''Flashbulb Memories,''* pp. 9–31. Cambridge: Cambridge University Press.
Niedenthal P and Halberstadt J (2000) Grounding categories in emotional response. In: Forgas JP (ed.) *Feeling and Thinking: The Role of Affect in Social Cognition*, pp. 357–386. New York: Cambridge University Press.
Niedenthal PM and Setterlund MB (1994) Emotion congruence in perception. *Pers. Soc. Psychol. Bull.* 20: 401–411.
Ost J, Costall A, and Bull R (2002) A perfect symmetry? A study of retractors' experiences of making and then repudiating claims of early sexual abuse. *Psychol. Crime Law* 8: 155–181.
Parrott WG and Sabini J (1990) Mood and memory under natural conditions: Evidence for mood incongruent recall. *J. Pers. Soc. Psychol.* 59: 321–336.
Phelps EA (2006) Emotion and cognition: Insights from studies of the human amygdala. *Annu. Rev. Psychol.* 24: 27–53.
Polivy J and Doyle C (1980) Laboratory induction of mood states through the reading of self-referent mood statements:

Affective changes or demand characteristics?. *J. Abnorm. Psychol.* 89: 286–290.
Poole DA, Lindsay DS, Memon A, and Bull R (1995) Psychotherapy and the recovery of memories of childhood sexual abuse: US and British practitioners' opinions, practices, and experiences. *J. Consult. Clin. Psychol.* 63: 426–437.
Pope HG Jr, Oliva PS, and Hudson JI (1999) Repressed memories: The scientific status. In: Faigman DL, Kaye DH, Saks MJ, and Sanders J (eds.) *Modern Scientific Evidence: The Law and Science of Expert Testimony,* vol. 1, pp. 115–155. St. Paul: West Publishing.
Pyszczynski T and Greenberg J (1987) Self-regulatory preservation and the depressive self-focusing style: A self-awareness theory of reactive depression. *Psychol. Bull.* 102: 122–138.
Rapaport D (1942/1961) *Emotions and Memory*. New York: Science Editions.
Razran GHS (1940) Conditioned response changes in rating and appraising sociopolitical slogans. *Psychol. Bull.* 37: 481–493.
Roediger HL and Bergman ET (1998) The controversy over recovered memories. *Psychol. Public Policy Law* 4: 1091–1109.
Roediger HL and McDermott KB (1995) Creating false memories: Remembering words not presented in lists. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 803–814.
Ruiz-Caballero JA and Gonzalez P (1994) Implicit and explicit memory bias in depressed and non-depressed subjects. *Cogn. Emot.* 8: 555–570.
Russell JA and Feldman Barrett L (1999) Core affect, prototypical emotional episodes and other things called emotion: Dissecting the elephant. *J. Pers. Soc. Psychol.* 76: 805–819.
Russell JA and Lemay G (2000) Emotion concepts. In: Lewis M and Haviland-Jones JM (eds.) *Handbook of Emotions,* 2nd edn., pp. 491–503. New York: Guilford.
Rusting CL (2001) Personality as a mediator of affective influences on social cognition. In: Forgas JP (ed.) *Handbook of Affect and Social Cognition*, pp. 371–391. Mahwah, NJ: Erlbaum.
Schacter DL (1995) Memory wars. *Sci. Am.* 272: 135–139.
Schacter DL (1999) The seven sins of memory: Insights from psychology and cognitive neuroscience. *Am. Psychol.* 54: 182–203.
Schiffenbauer AI (1974) Effect of observer's emotional state on judgments of the emotional state of others. *J. Pers. Soc. Psychol.* 30: 31–35.
Schooler JW (2001) Discovering memories of abuse in the light of meta-awareness. In: Freyd JJ and DePrince AP (eds.) *Trauma and Cognitive Science: A Meeting of Minds, Science, and Human Experience*, pp. 105–136. New York: Haworth.
Schooler JW and Eich E (2000) Memory for emotional events. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 379–392. New York: Oxford.
Schooler JW, Ambadar Z, and Bendiksen MA (1997) A cognitive corroborative case study approach for investigating discovered memories of sexual abuse. In: Read JD and Lindsay DS (eds.) *Recollections of Trauma: Scientific Research and Clinical Practice*, pp. 379–388. New York: Plenum.
Schwarz N (1990) Feelings as information: Informational and motivational functions of affective states. In: Higgins ET and Sorrentino R (eds.) *Handbook of Motivation and Cognition,* vol. 2, pp. 527–561. New York: Guilford.
Schwarz N and Clore GL (1983) Mood, misattribution and judgments of well-being: Informative and directive functions of affective states. *J. Pers. Soc. Psychol.* 45: 513–523.
Schwarz N and Clore GL (1988) How do I feel about it? The informative function of affective states. In: Fiedler K and Forgas JP (eds.) *Affect, Cognition, and Social Behavior*, pp. 44–62. Toronto: Hogrefe.
Scott S (2001) *The Politics and Experience of Ritual Abuse: Beyond Disbelief*. Buckingham, UK: Open University Press.
Sedikides C (1994) Incongruent effects of sad mood on self-conception valence: It's a matter of time. *Eur. J. Soc. Psychol.* 24: 161–172.
Sedikides C (1995) Central and peripheral self-conceptions are differentially influenced by mood: Tests of the differential sensitivity hypothesis. *J. Pers. Soc. Psychol.* 69: 759–777.
Shobe KK and Kihlstrom JF (1997) Is traumatic memory special? *Curr. Dir. Psychol. Sci.* 6: 70–74.
Shobe KK and Schooler JW (2001) Discovering fact and fiction: Case-based analyses of authentic and fabricated memories of abuse. In: Davies GM and Dalgleish T (eds.) *Recovered Memories: Seeking the Middle Ground*, pp. 95–151. Chichester, UK: John Wiley and Sons.
Singer JA and Salovey P (1988) Mood and memory: Evaluating the network theory of affect. *Clini. Psychol. Rev.* 8: 211–251.
Smeets T, Merckelbach H, Horselenberg R, and Jelicic M (2005) Trying to recollect past events: Confidence, beliefs, and memories. *Clin. Psychol. Rev.* 25: 917–934.
Smith SM and Petty RE (1995) Personality moderators of mood congruency effects on cognition: The role of self-esteem and negative mood regulation. *J. Pers. Soc. Psychol.* 68: 1092–1107.
Talarico JM and Rubin DC (2003) Confidence, not consistency, characterizes flashbulb memories. *Psychol. Sci.* 14: 455–461.
Tobias BA, Kihlstrom JF, and Schacter DL (1992) Emotion and implicit memory. In: Christianson S-A (ed.) *Handbook of Emotion and Memory*, pp. 67–92. Hillsdale, NJ: Erlbaum.
Van der Kolk BA (1996) Trauma and memory. In: van der Kolk BA, McFarlane AC, and Weisaeth L (eds.) *Traumatic Stress: The Effects of Overwhelming Experience on Mind, Body, and Society*, pp. 279–302. New York: Guilford.
Wade K, Garry M, Read JD, and Lindsay DS (2002) A picture is worth a thousand lies. Using false photographs to create false childhood memories. *Psychon. Bull. Rev.* 9: 597–603.
Watkins T, Mathews AM, Williamson DA, and Fuller R (1992) Mood congruent memory in depression: Emotional priming or elaboration. *J. Abnorm. Psychol.* 101: 581–586.
Watts FN and Dalgleish T (1991) Memory for phobia related words in spider phobics. *Cogn. Emot.* 5: 313–329.
Williams LM (1994) Recall of childhood trauma: A prospective study of women's memories of child sexual abuse. *J. Consult. Clin. Psychol.* 62: 1167–1176.
Wyer RS and Srull TK (1989) *Memory and Cognition in Its Social Context*. Hillsdale, NJ: Erlbaum.
Yuille JC and Cutshall JL (1986) A case study of eyewitness memory of a crime. *J. Appl. Psychol.* 71: 291–301.

# 2.16 Retrieval Processes in Memory

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## 2.16.1 Retrieval Processes in Memory

A dominant framework during the past four decades has postulated three critical components to understanding memory – encoding, storage, and retrieval. But the relative importance that researchers have attributed to each of these components has varied over the course of history. In his 2000 chapter for the Tallinn Conference, Roediger traced this history by taking as his departure point Endel Tulving's remark, "the key process in memory is retrieval." Roediger noted that, despite the fact that the role of retrieval had been emphasized since the writings of Wolfgang Kohler (1947) and Richard Semon (1921; see Schacter, 1982, 2001; Schacter et al., 1978), the belief that encoding and storage processes are the key components of memory has persisted through recent history. Roediger then elaborated both the logical and empirical arguments to demonstrate why retrieval is the key process for understanding human memory (Roediger and Guynn, 1996; Roediger, 2000). The purpose of the current chapter is to reinforce and expand upon this argument.

It is reasonable to assume that without encoding and storage of information there can be no retrieval. But the converse is truer – without retrieval there is no evidence that either encoding or storage ever occurred. Furthermore, retrieval can occur even in the absence of encoding, as in the case of false memories. Retrieval processes thus provide a measure of not only what was encoded and stored but also of what constitutes memory from the perspective of the rememberer – regardless of the reality of that memory. In essence, retrieval then is the measure of memory.

In emphasizing the importance of retrieval processes, Tulving and Pearlstone (1966) proposed a critical distinction between the availability and the accessibility of information. Importantly, they proposed that what is available in memory cannot be known unless that information is accessed. If accessibility is the key to determining the availability of memory, then how can we determine what is accessible? The answer to this question depends on our understanding of the retrieval conditions that can successfully detect encoding and storage. In other words, our measure of what is available in memory is contingent on being able to arrange retrieval conditions that can elicit available memories. It follows then that an understanding of retrieval processes is crucial for understanding the nature of memory.

In this chapter, we have organized the discussion of retrieval processes into six sections: (1) task differences – the role of retrieval cues, (2) encoding and retrieval interactions, (3) retrieval mode, (4) repeated retrieval, (5) retrieval in a social context, and (6) retrieval errors and other retrieval effects. Many of these sections are the very topics of some of the other chapters in this volume and are covered comprehensively in those chapters. We bring together these topics here to evaluate their significance specifically in the context of retrieval and to determine how these phenomena and processes reveal something about the nature of retrieval process *per se.*

## 2.16.2 Task Differences – The Role of Retrieval Cues

Numerous studies have now amply demonstrated the critical role retrieval cues play in revealing availability of memory. These studies were inspired by a wide variety of theoretical frameworks, and as such they can be organized under a number of different subtopics. Regardless of the theoretical perspectives that inspired these studies – and we will discuss some of these perspectives in the course of this chapter – we include them here because they also underscore the importance of retrieval cues.

Some retrieval cues are internal, as in the case of the most quintessential of all memory tasks, free recall. In this task, participants are given no cues and are asked to write down all the studied information that they were presented earlier. As such, participants rely on their own internal resources – strategies, organization, and cues – to report studied information while performing the free recall task. Retrieval cues can also be external, and in this case the variety of retrieval tasks designed with different cues can span a wide realm, depending on the experimenter's theoretical needs. The most common of such tasks are cued recall and recognition, and we will discuss some findings that show the efficacy of these tasks in improving accessibility to learned information.

In their seminal study, Tulving and Pearlstone (1966) reported the extent to which accessibility can differ just between free-recall (where the cues are internal) and cued-recall (where the cues are external) tasks. In this experiment, participants studied categorized word lists, which consisted of a category name followed by a list of words (of varying length – 12, 24, or 48 words per list) that represented instances of that category. Later the participants were given either a free-recall test or a cued-recall test, the difference between these two tests being that the cued-recall test provided participants with the category names of each word list. Results indicated that participants were able to recall many more words under cued-recall conditions than under free-recall conditions. Furthermore, the benefit of cued recall over free recall increased as the number of words on the to-be-remembered list increased. These results have been interpreted as evidence that not all information that is available is also accessible. Accessibility depends upon the type of cues provided at test.

This demonstration can be expanded by adding tasks that provide even more external cues than those used in the category/cued-recall task. Under such conditions, we would expect memory output to increase as the information provided by the retrieval cues increases – as long as the encoding conditions across these memory tasks remain the same. This scenario can be found in another landmark paper by Tulving (1985), where he introduced the remember–know paradigm. We will discuss this paradigm in a later section on 'Retrieval mode,' but for now, we focus on the inclusion of a third task in Tulving's study. Subjects first studied category names and exemplars (musical instrument–viola) and later completed three successive memory tasks – free recall, category-cued recall (where the category name served as the retrieval cue, e.g., musical instrument–__________), and category plus letter recall (where, in addition to the category name, the first letter of the exemplar was also presented as the retrieval cue, e.g., musical instrument–v________). As the retrieval cues increased, so did the memory output. A recent study in our lab (Hamilton and Rajaram, 2003) replicated and extended this pattern by adding a fourth memory task to the mix – the recognition-memory task. In this task, the test cues completely recapitulate the study cues and by so doing provide maximal assistance for retrieval. We changed the design further by conducting these tests in a between-subjects design such that successive retrieval was not required and the efficacy of different cues could be assessed without contamination from the other retrieval tasks. Our aim in expanding and changing the design concerned issues of memory experience that we do not discuss here. Instead, we focus here on the overall memory performance across the four tasks. With our design, we replicated and expanded on Tulving's (1985) results such that memory output increased as retrieval cues increased, with the highest level of performance occurring in the recognition task (mean proportions of total items correctly retrieved: free recall = .21; category-cued recall = .40; category plus letter-cued recall = .56; recognition = .87 (Hamilton and Rajaram, 2003, Experiment 2), collapsed across the levels of processing manipulation discussed in the next section). Our results further illustrate how retrieval cues can change accessibility. We will return to role of retrieval cues in a later section on retrieval modes.

To summarize, as the number of cues available at retrieval increases, so does the memory output. This fact is important in distinguishing between memories that are available but simply inaccessible. Information that cannot be recalled during a free-recall task may be available, but currently inaccessible. That same information may be recalled during a recognition task.

## 2.16.3 Encoding and Retrieval Interactions

Studies discussed in the previous section show how increased retrieval cues can improve memory performance. This conclusion rests on the assumption that, when retrieval cues are varied, the encoding conditions are held constant. This assumption is the converse of a popular approach where encoding conditions are varied while the retrieval task is held constant. One of the most robust and enduring examples of the latter approach is the levels-of-processing paradigm. In their classic paper, Craik and Lockhart (1972) presented the levels-of-processing framework in which information encoded for its meaning is predicted to be more memorable than information processed at more 'shallow' levels such as focusing on the sound of the word or the letter patterns. This pattern of performance has now been replicated hundreds of times and is routinely observed in the standard memory tasks (Lockhart and Craik, 1990). For example, in the second experiment of our study described in the previous section (Hamilton and Rajaram, 2003), we observed the levels-of-processing effect within each of the four retrieval tasks – free recall, category-cued recall, category-plus-letter recall, and recognition. That is, within each task the level of memory output was consistently higher for items encoded for meaning than for items encoded at a shallow level. Even so, as we noted before, memory output increased as retrieval cues increased, and this pattern was true both for items that were encoded at a deep level and for items encoded at a shallow level.

Yet task differences can change memory accessibility in another way – different retrieval cues can interact differently with the encoded information when the encoding is also varied. Such encoding–retrieval interactions change memory performance in specific ways in contrast to the general effects illustrated in the empirical example above. The idea of encoding–retrieval interactions is embodied in the encoding specificity principle (Tulving and Osler, 1968; Tulving and Thomson, 1973; Tulving, 1974) and the transfer-appropriate processing framework (Morris et al., 1977; Roediger et al., 1989) – two theoretical approaches that inspired extensive research and have unraveled yet another layer of mystery about memory functions.

### 2.16.3.1 The Encoding Specificity Principle

Studies inspired by the encoding specificity principle have shown findings that seem counterintuitive in the context of the memory effects we discussed in the previous section. It turns out that, contrary to general expectations, an increase in retrieval cues or the provision of strong retrieval cues does not always produce the best memory performance. This is because strong cues are not always the best match for the study material. In a now classic study, Thomson and Tulving (1970) reported the highly counterintuitive finding that even the absence of retrieval cues can sometimes produce better memory than the presence of retrieval cues. Furthermore, strong retrieval cues can be sometimes *less* effective than weak retrieval cues. The design of this study went like this. During encoding, participants studied a list of words that were presented either alone (e.g., BLACK), with a weak associate (e.g., train – BLACK), or with a strong associate (e.g., white – BLACK). Later participants were given one of three types of recall tests – a free-recall test, a cued-recall test with weak associates serving as the recall cues, or a cued-recall test with strong associates serving as the recall cues. Results of this study indicated that it was the degree of match between cues at study and test (rather than the strength of preexisting associations between the cue and test word) that determined recall (**Table 1**). Strong associates aided recall if they were also given at encoding. However, if weak associates were given at encoding, strong associates as test cues hurt recall. In other words, a retrieval cue is effective if and only if it reinstates the original encoding (see also Tulving and Thomson, 1973).

**Table 1** Mean number of words recalled across various encoding and retrieval conditions

| | *Retrieval condition* | | |
|---|---|---|---|
| *Encoding condition* | *Free recall* | *Cued recall with weak associate* | *Cued recall with strong associate* |
| Word only | 14.1 | 11.1 | 19.0 |
| Word with weak associate | 10.7 | 15.7 | 13.9 |
| Word with strong associate | 12.2 | 9.2 | 20.2 |

Adapted from Experiment 1 in Thomson DM and Tulving E (1970) Associative encoding and retrieval: Weak and strong cues. *J. Exp. Psychol.* 86(2): 255–262.

As Tulving (1983) pointed out, the locus of the memory effect then is neither at encoding nor at retrieval *per se* but in the interaction between the two. It is reasonable to wonder at this point whether such an interaction undermines the case that retrieval is the key process for understanding memory. To the contrary, such findings underscore the importance of arranging the retrieval conditions that maximally exploit the features of the encoding conditions. This requirement becomes increasingly important as researchers explore the effects of increasingly complex variables – both at encoding and at retrieval – such as place and the internal state of the individual. We review a selection of studies here to illustrate this point and refer the reader to a comprehensive review by Roediger and Guynn (1996) on this subject.

A number of these studies have used the encoding–retrieval paradigm that Tulving (1983) proposed, where both encoding and retrieval conditions are experimentally manipulated. In its most basic form, it involves an encoding experiment with two (or more) encoding conditions (e.g., A and B) and a retrieval experiment with two (or more) retrieval conditions (e.g., X and Y) being conducted simultaneously. By examining only how A differs from B we are able to determine the influence of encoding. Similarly, by examining only how X differs from Y we are able to determine the influence of retrieval. By manipulating both encoding and retrieval conditions simultaneously we are able to examine the interaction between encoding and retrieval conditions. For example, in the study by Thomson and Tulving (1970) just described, encoding conditions were manipulated such that the words were studied under one of three circumstances (word alone, word paired with a weak associate, or word with a strong associate). Similarly, retrieval conditions were also manipulated. Participants were given either a free-recall test, a cued-recall test with the weak associates as cues, or a cued-recall test with the strong associates as cues. It is only by examining the interaction between encoding and retrieval conditions that Thomson and Tulving (1970) were able to observe support for the encoding specificity principle.

#### 2.16.3.1.1 Place-dependent memory

The introduction of the encoding–retrieval paradigm inspired several studies that focused on two sets of variables – place and internal state – to test the encoding specificity principle. These variables carry wide appeal because they are complex and close to real life. In a frequently cited study, Godden and Baddeley (1975) examined the effects of matching or mismatching the place – including the environment – on memory in a rather interesting way. In their study, subjects studied a list of 36 words either on dry land or under water (**Table 2**). These encoding conditions were later crossed with two retrieval conditions in a 2 × 2 factorial design such that subjects performed a free recall task either in the same place/environment as the encoding condition (dry land–dry land or underwater–underwater) or in a different place/environment (dry land–underwater or underwater–dry land). The findings revealed what is known as place-dependent memory and were consistent with the encoding specificity principle; recall was best when the place/environment matched across study and test regardless of whether the place was on land or underwater.

Researchers have also examined place-dependent memory using more common places such as classrooms

**Table 2** Mean number of words recalled in Expt. 1 as a function of learning and recall environment

| | *Recall environment* | |
|---|---|---|
| *Learning environment* | *Dry* | *Wet* |
| Dry | 13.5 | 8.6 |
| Wet | 8.4 | 11.4 |

Adapted from Experiment 1 in Godden DR and Baddeley AD (1975) Context-dependent memory in two natural environments: On land and underwater. *Br. J. Psychol.* 66(3): 325–331.

(Smith et al., 1978). In a series of experiments, Smith et al. showed that the environmental context effects (manipulated in their study by changing or keeping constant the classroom in which study and test took place) occur reliably. Furthermore, these context effects emerged even if the subjects did not perform the retrieval task in the same room as long as they imagined being in the same room while taking the test. This finding is intriguing because it suggests a strong role of the internal resources in mediating effects related to the external environment.

This implication – that internal resources play an important role in encoding–retrieval interactions – is consistent with the observations that the effects of the encoding–retrieval match are often task dependent. It turns out that place- and context-match effects occur more reliably in free recall but rarely in recognition (see Smith, 1988). This pattern makes sense if internal resources are critical for the encoding–retrieval interactions to occur, because free recall requires internal generation of context, associations, and thoughts, whereas recognition is driven at least in part by the external cues provided to the subject. A number of studies have since reinforced the importance of internal resources in mediating the place-dependent memory effects (Eich, 1985; Fernandez and Glenberg, 1985; McDaniel et al., 1989). As we will see shortly, task selection at retrieval seems to play a significant role in mood-dependent memory as well. Once again, this pattern points to the role of internal origins in mediating the encoding–retrieval interaction effects.

#### 2.16.3.1.2 State-dependent memory

The impact of two interrelated factors we have just discussed – type of retrieval tasks and the involvement of internal resources – has also emerged in two other domains of encoding–retrieval interactions, both of which can be subsumed under the construct of internal states. One concerns state-dependent memory and the other concerns mood-dependent memory. The effects of state-dependent memory have been reported in studies that involved the administration of drugs such as alcohol (e.g., Lowe, 1982) or marijuana. For example, in a study that administered marijuana (e.g., Eich et al., 1975; Eich, 1980), participants encoded information either in a drug state (20 minutes after smoking a marijuana cigarette) or in a sober state (20 minutes after smoking a cigarette that only tasted like a marijuana cigarette). Later, there were four possible recall conditions such that type of test (either free-recall or a category-name cued-recall test) and physiological state (either same as encoding or different from encoding) were crossed with one another. The results indicated that a change of pharmacological state from encoding to retrieval impaired performance on a free-recall test but not on a cued-recall test. Further, even with free recall, it is important to note that drug states, even when matched across study and test, are not the best for improving memory because the best recall was observed when information was both encoded and retrieved in a sober state. Returning to the comparison between free- and cued-recall tasks, the general conclusion of these results was that internal state can sometimes serve as a memory cue (as is the case with the free-recall results of this experiment). However, when there are more effective external cues (such as category names) people do not use the less-effective internal cues (as in the case with the cued-recall results of this experiment).

#### 2.16.3.1.3 Mood-dependent memory

We now turn to mood-dependent effects on memory. These effects are especially intriguing because people have an intuitive sense that memory must be sensitive to how we feel when we learn and when we retrieve the learned information. As we discussed earlier, internal context seems to be quite important for understanding encoding–retrieval interactions, and mood certainly provides a prototypical example of internal context (see Eich, 1985). Yet it turns out that findings in this area of research reveal a complex relationship between mood and memory.

Mood is usually manipulated in studies by using hypnotic suggestion, happy/sad music, or comic/sad video clips, and rating scales are often used to measure the attainment of mood. Early studies reported promising results in that mood match across study and test produced better memory performance. For instance, one study reported such effects in endogenously occurring mood states where psychiatric subjects reproduced more free associations if their mood (manic or normal) matched across the first and second attempts than if it mismatched (Weingartner et al., 1977). In another study, Bower et al. (1978) manipulated happy or sad mood through hypnotic suggestion and observed substantially higher recall of common words had they been studied and tested in the same mood than in different moods. But the empirical story got murky thereafter and led researchers to question mood-dependent memory effects (see Blaney, 1986). In fact, in a later study, Bower and Mayer (1989) failed to replicate the mood-dependent memory effect, and similar failures to replicate started to accumulate in the literature (see Eich, 1995b, for a review).

Two phenomena subsequently clarified when the mood-dependent memory effect is likely to occur, and both of these phenomena are consistent with the notion that internal context (or internal state) is important for observing the expected encoding–retrieval interaction in mood studies. In one study, Eich and Metcalfe (1989) asked subjects to either read the to-be-recalled targets (cold) or generate them from semantically related cues (hot-???). Subjects performed this task in either pleasant or unpleasant moods induced through different types of music. Subjects were later induced to experience the same mood or a different mood before recalling the word pairs under conditions of free recall. Mood-dependent effects appeared only for items that were generated during study and not for items that were simply read (**Table 3**). The authors replicated these findings in other experiments within the series, and this effect has since been replicated by others as well (Beck and McBee, 1995).

Taking a different approach, Eich et al. (1994) investigated this question by asking subjects to generate events from their own lives. The experimenters manipulated mood by inducing either a pleasant or an unpleasant mood while subjects performed this task. Later, subjects were asked to recall the gist of events they had generated earlier while experiencing either the same mood as before or a different mood. Two interesting effects emerged: (1) in the first session, subjects generated events that were consistent with their mood (either pleasant or unpleasant), producing a mood congruency effect (Blaney, 1986); (2) in the second session, subjects were better at recalling those events that matched their mood at retrieval than they were at those that mismatched, thereby producing a mood-dependent memory effect. These studies emphasize the special role of internal states in producing mood effects in line with Eich and Metcalfe's arguments that mood-dependency effects only occur for self-generated activities (i.e., for internally generated thoughts) and not for externally produced events. Furthermore, the role of internal resources becomes even more important when we consider the nature of the retrieval task that effectively produces these effects. As with place-dependent memory, mood-dependent memory effects are also observed more reliably in free recall than in recognition (Eich and Metcalfe, 1989). At a broader level, this cluster of findings from manipulations of place, state, and mood lends further support to the theme that internal resources play an important role in mediating encoding–retrieval interactions.

**Table 3** Probability of recall as a function of item type and encoding/retrieval condition

| | *Test condition* | | | |
|---|---|---|---|---|
| | *Read words* | | *Generated words* | |
| *Encoding condition* | *Happy* | *Sad* | *Happy* | *Sad* |
| Happy | .09 | .04 | .32 | .17 |
| Sad | .05 | .07 | .17 | .27 |

Adapted from Experiment 1 in Eich E and Metcalfe J (1989) Mood dependent memory for internal versus external events. *J. Exp. Psychol. Learn. Mem. Cogn.* 15(3): 443–455.

The place-, state-, and mood-dependent memory effects reviewed so far show the complexities involved in studying variables that are multidimensional. Their complexities pose a challenge to researchers in being able to reinstate the exact conditions across study and test. In fact, some of these variables can sometimes be confounded with each other such that one variable (e.g., mood) can mediate the effects of another variable (e.g., state) and further complicate our understanding of encoding–retrieval interactions. For example, Eich (1995a) has argued that place-dependent memory is actually just a special case of mood-dependent memory. In an experiment examining this hypothesis (Eich, 1995b, Experiment 3), participants generated autobiographical events in a pleasant environment and in a pleasant mood. Later, they were asked to recall this information in one of four distinct conditions defined by the 2 × 2 factorial combination of (1) same versus different place and (2) same versus different mood. In this study, it made no difference whether participants were tested in the same versus a different place. However, there was a significant difference when participants were tested in the same mood (55% recall) versus a different mood (45% recall). Based upon these results, it is possible to conclude that how well information transfers from one place to another depends not on how similar the two locations look, but rather on how similar the two locations feel. A similar argument has been set forth regarding state-dependent memory effects. The drugs that most reliably produce state-dependent retrieval effects (such as alcohol and amphetamines) are accompanied by large mood changes. This led Bower (1981) to conclude that state-dependent effects are achieved as a result of the confounded mood-dependent effects.

In brief, thus far in this section, we have reviewed classic and representative studies that show how encoding and retrieval interactions reveal effects of specificity in memory. Together, studies on place-dependent, state-dependent, and mood-dependent memory also show the importance of the types of cue and the task selection at retrieval for detecting these patterns of specificity.

#### 2.16.3.2 The Transfer-Appropriate Processing Framework

The encoding specificity principle proposes that memories are associated with particular cues, and recall is predicted to be enhanced if the cues at retrieval are the same as those that were encoded in the memory traces formed at encoding. We now turn to a discussion of another influential approach – known as the transfer-appropriate processing framework (Roediger et al., 1989; Roediger, 1990) – that is similar to the encoding specificity principle but emphasizes the processes and procedures of mind (Kolers and Roediger, 1984) rather than its structural contents to explain the interactions between encoding and retrieval. In this processing approach, recall is predicted to be enhanced when the processing at retrieval is the same type of processing as encoding. For example, this approach predicts superior memory for 'shallow' encoding of items if the retrieval task capitalizes on the processing of shallow aspects of the study material (Morris et al., 1977; Roediger et al., 1989). This prediction is at odds with the classic and robust demonstrations of the levels of processing effect we discussed earlier, where information processed for meaning is retrieved better than information processed for its shallow aspects such as phonemic details (Craik and Lockhart, 1972; Craik and Tulving, 1975). But the two phenomena can be reconciled if we take into account the critical role retrieval processes play in tapping the encoded information. In their study, Morris et al. (1977) factorially varied the type of encoding task with the type of retrieval task. In particular, during encoding, participants were asked to determine either whether a given word fit into a sentence (a deep semantic encoding task) or whether it rhymed with another word (a shallow phonetic encoding task). Later, participants were either given a standard recognition task or a recognition task involving rhymes (i.e., "does this word rhyme with a previously seen word?"). When the encoding rhyme questions required 'yes' judgments ("does dog rhyme with hog"?), a very interesting pattern of results emerged on the later memory tasks; while semantic acquisition was superior to rhyme acquisition when tested using a standard recognition task, the converse was true when tested using the rhyme recognition task. Based upon these results, Morris and colleagues concluded that shallow encoding is not necessarily inferior to deep encoding and that the effectiveness of any given encoding task depends upon the relationship between the encoding task and retrieval task.

In the late 1980s and early 1990s, Roddy Roediger and his colleagues (Roediger et al., 1989; Roediger, 1990) published a comprehensive framework for testing the principles of transfer-appropriate processing. This framework inspired an empirical revolution that sought to specify the nature of encoding and retrieval processes and the ways in which the selection of these processes can impair or maximize memory performance. A full description of this framework, its tenets, and the major findings are beyond the scope of this chapter, but we recommend several comprehensive reviews to the reader on the theoretical and empirical developments in this area of research (Roediger et al., 1989, 1990; Roediger, 1990; Roediger and McDermott, 1993). In brief, this framework states that memory performance improves to the extent that cognitive processes engaged during test match the processes that were engaged during study. Consistent with this main tenet, extensive research has now shown that subtleties in the match or mismatch of processes during encoding and retrieval can produce large effects on memory performance. As a result, it is critical to select retrieval tasks that closely match the encoding task in their processing requirements. We will discuss some empirical illustrations of this key conclusion in the next section, where we describe the impact of retrieval mode on memory performance.

To briefly summarize the arguments thus far, the encoding specificity principle postulates that memory is enhanced when the cues at recall match the cues at encoding (as is the case in place-, state-, and mood-dependent memory). In a similar vein, the transfer-appropriate processing approach postulates that memory is enhanced when the processes engaged during recall match the processes engaged during encoding. Together, these studies demonstrate the importance of arranging the retrieval conditions so that we can optimize accessibility to learned information.

## 2.16.4 Retrieval Mode

In his chapter for the Tallinn conference, Roediger (2000) discussed the concept of retrieval mode and its power to reveal aspects of memory that might otherwise remain concealed. We expand upon this notion in this section. We will consider the significance of retrieval mode from two perspectives that Roediger noted: (1) explicit and implicit modes of retrieval and (2) remembering and knowing information from the past. Each perspective has brought into focus many important questions concerning retrieval and has led to substantial empirical and theoretical developments on these issues. We refer the reader to two directly relevant chapters in this volume that tackle each of these topics in depth – one by D. L. Schacter on implicit memory (*See* Chapter 2.33) and another by J. M. Gardiner on remembering and knowing (*See* Chapter 2.17). In this section, we discuss a few examples to demonstrate how a change in the retrieval mode can bring about changes in accessibility to studied information.

### 2.16.4.1 Explicit versus Implicit Memory

The relevance of task differences and encoding–retrieval interactions in improving accessibility comes together in rather dramatic ways when we consider the explicit versus implicit modes of retrieval in which people engage while doing memory tasks. In their seminal papers, Warrington and Weiskrantz (1968, 1970) reported findings that nicely illustrate how retrieval mode can affect the memory product. In these studies, amnesic subjects performed poorly, as would be expected, when asked to think back on the study episode and recall what was studied (as in free recall). But these subjects exhibited, rather surprisingly, normal memory performance when they were asked to complete a memory task with the first response in the manner of problem solving (for example, complete the physically impoverished cues in a word fragment completion task with the first response that comes to mind). Graf and Schacter (1985) introduced the distinction between explicit and implicit memory to respectively capture this difference between a mode of retrieval where people think back on the study episode (all the memory tasks discussed in the other sections of this chapter) and a mode where no reference is made to study episode during test performance.

These differences in the retrieval task instructions can change memory performance of not only individuals who have amnesia but also individuals who possess intact memory functions (see Schacter, 1987, 1990; Roediger et al., 1989, 1990; Roediger, 1990; Roediger and McDermott, 1993, for representative reviews.) We will discuss some findings observed in individuals with intact memory to elaborate this point. In the previous section, we discussed the classic levels of processing effect on tasks such as free recall and recognition (Craik and Tulving, 1975) and the reversal of this effect when the recognition task provided phonemic cues as opposed to the standard cues (Morris et al., 1977). Interestingly, the conceptual advantage of levels of processing disappears if test conditions require implicit retrieval in response to perceptual test cues. In other words, on tasks such as word identification (reading words presented rapidly at threshold durations), word fragment completion (presenting test cues with some letters missing, e.g., _ t r _ _ b _ r _ _), or word stem completion (str_______), completing the cues with the first solution that comes to mind confers little advantage for words studied for meaning compared to words studied for their perceptual features (e.g., Jacoby and Dallas, 1981; Graf and Mandler, 1984; Roediger et al., 1992). Thus, the levels of processing effect can vary as a result of the tasks used; it occurs on free recall and recognition (Craik and Tulving, 1975), reverses on a phonemic cued-recall task (Morris et al., 1977), and disappears on implicit tasks that rely on perceptual processes for completion. These findings once again highlight the importance of retrieval cues in accessing learned information.

The disappearance of study differences on implicit tasks can change the way we theorize about the significance of encoding (or storage) versus retrieval. For instance, the advantage in free recall for concrete words (such as table, bus, strawberry – words that can be imaged or represented as objects) over abstract words (such as pledge, destiny, care) has been attributed to dual storage of concrete words in verbal and image codes compared to single representations of abstract words (only verbal code) (Paivio et al., 1968; Paivio, 1969). Yet, in a study from our lab (Hamilton and Rajaram, 2001) we found that on implicit tests such as word fragment completion (_ t r _ _ b _ r _ _) and implicit general knowledge test (what fruit wears its seeds on its skin?), there was an equivalent

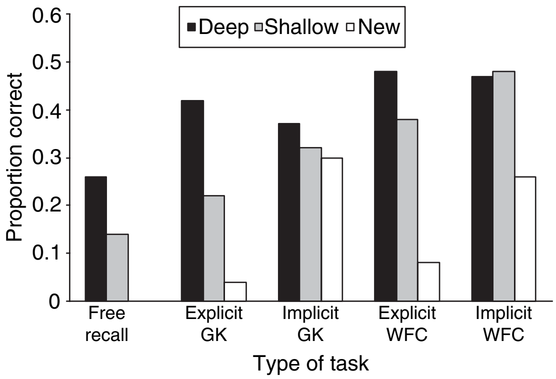


**Figure 1** Mean proportion of correct responses for each item type for each of the five tasks used (GK, general knowledge task; WFC, word fragment completion task). Adapted from Experiment 2 in Hamilton M and Rajaram S (2001) The concreteness effect in implicit and explicit memory tests. *J. Mem. Lang.* 44(1): 96–117.

advantage for producing studied concrete words and studied abstract words over their nonstudied counterparts (**Figure 1**). In other words, on an implicit memory task there was no memorial benefit of concrete words over abstract words. Therefore, the concrete/abstract distinction in memory cannot be discussed only in the context of differential encoding or storage. This distinction demands a more complex explanation because this effect is not ubiquitous – it can be specific to a particular mode of retrieval.

A converse pattern can also emerge by changing the retrieval mode such that some study differences do not affect explicit memory but produce changes in implicit memory. For example, changing the modality of presentation at study – presenting words either in the auditory or the visual modality – does not change the level of free recall (Blaxton, 1989; Srinivas and Roediger, 1990; Rajaram and Roediger, 1993), and this null finding suggests that modality of presentation at study does not matter. However, this conclusion is only partly correct as we (Rajaram and Roediger, 1993) found in our study with four different implicit tasks involving perceptual cues (see **Figure 2**). When subjects were presented with impoverished cues such as word fragments, word stems, rapidly presented words in the word identification task, or anagrams (brtaserwyr) to solve in the anagram solution task (strawberry) and were asked to perform these tasks with the first solution that comes to mind, performance improved on these implicit tests if the study and test materials were presented in the same modality compared to different modalities (see also Jacoby and Dallas, 1981; Kirsner et al., 1983; Graf and Mandler, 1984; Roediger and Blaxton, 1987; Blaxton, 1989; Srinivas and Roediger, 1990; Weldon, 1991). In other words, the impact of a study variable is sometimes detectable only when subjects used the implicit retrieval mode. (As an aside, but consistent with the general argument about the impact of retrieval cues in modulating memory performance, we also found that studied pictures produced the worst performance on these implicit tasks that provided word-based cues. This, of course, is contrary to the pattern that is typically observed in free recall and recognition, where memory for pictures is better than that for words (Paivio et al., 1968; Madigan, 1983; Weldon and Roediger, 1987; Rajaram, 1993).)

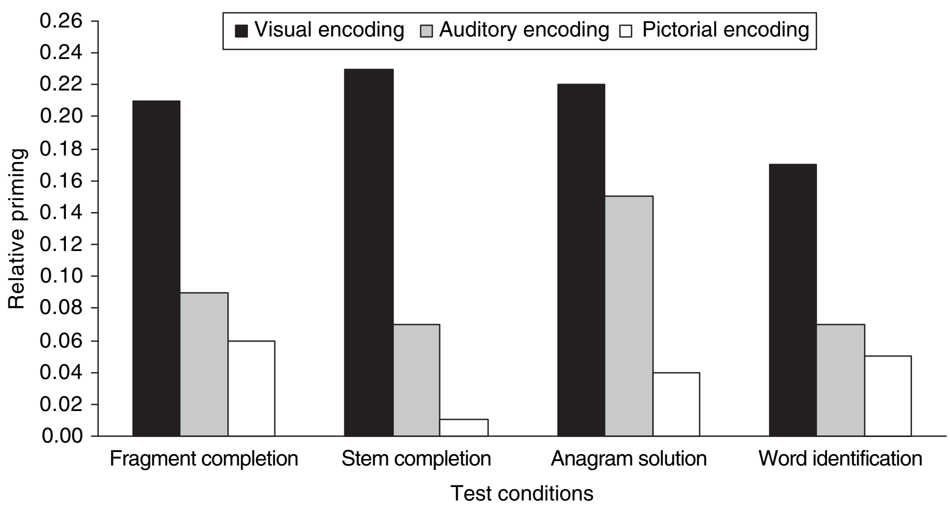


**Figure 2** Relative priming for the four implicit memory tasks across different encoding conditions. Adapted from Rajaram S and Roediger HL (1993) Direct comparison of four implicit memory tests. *J. Exp. Psychol. Learn. Mem. Cogn.* 19(4): 765–776.

The impact of retrieval mode on memory performance can be seen even when the retrieval cues themselves are held constant and only the mode of retrieval is varied through instructions, or when the retrieval intentionality criterion is met by the experimental conditions (Schacter et al., 1989). For example, when performance on free recall is contrasted with performance on a task such as implicit word fragment completion, the retrieval mode changes, but so do the test cues (no test cues in free recall and perceptually degraded cues in fragment completion, e.g., _ t r _ _ b _ r _ _). But the role of retrieval mode in detecting memory would be more persuasive if dissociations between explicit and implicit memory could be observed even when the same test cues were used in both conditions. Graf and Mandler (1984) reported such a dissociation between an explicit word stem cued-recall task and an explicit word stem completion task where the same test cues (e.g., ele_______) were used, and the levels of processing effect occurred on the explicit but not the implicit version of the task. In a large-scale study, Roediger et al. (1992) reported similar patterns of performance when they contrasted explicit and implicit versions of the test using identical stem cues (e.g., ele_______) as well as explicit and implicit versions of the test using identical fragment cues (e.g., _ l _ p _ a n _). Along the same lines, in our study with concrete and abstract words we just described, we found that the presence of the concreteness effect in free recall also extended to the explicit retrieval version of the general knowledge test (complete the following question with a studied word: "What fruit wears its seeds on its skin?") but, as noted earlier, not to the implicit version of the general knowledge test (Hamilton and Rajaram, 2001). In other words, we demonstrated dissociative effects on explicit and implicit versions of a different type of task, namely general knowledge, while holding the test cues constant (see again **Figure 1**).

### 2.16.4.2 Differentiating between Conceptual and Perceptual Retrieval Cues

While explicit and implicit retrieval modes can produce various dissociations of theoretical significance such as the ones just described, dissociations can also occur *within* one retrieval mode – for example, with differences in implicit retrieval cues provided to the participants. In previous sections, we described how differences in retrieval cues can bring about changes in memory performance within the context of explicit memory tasks such as free recall, cued recall, and recognition. The tenets of the transfer-appropriate processing framework (Roediger et al., 1989; Roediger, 1990) predict systematic differences even within implicit memory tasks, depending on the type of process demanded by the tasks. If the implicit memory task largely depends on perceptual processes for its successful completion – as in the cases of word fragment completion, word stem completion, perceptual identification tasks – then encoding orientation produces one type of effect. But if the implicit task mainly relies on conceptual processes – as in the cases of the general knowledge test described earlier and also tests such as implicit category association test (given a category name, participants are asked to produce all the exemplars that come to mind within 30 s) – then the same encoding orientation produces the opposite effect. So, for example, the modality effect observed across different *perceptual* implicit tasks described in the study by Rajaram and Roediger (1993) disappears on *conceptual* implicit tasks because changes in modality of presentation are not important for accessing meaning (e.g., Blaxton, 1989; Srinivas and Roediger, 1990). Encoding variables that differentiate the extent to which meaning (rather than surface information as in the modality manipulation) is varied during study produce the opposite effect: As we described earlier in this section, the levels-of-processing effect that reflects changes in conceptual processing of information disappears on *perceptual* implicit tasks. But this effect is reliably observed on *conceptual* implicit tasks such as the implicit general knowledge test (Hamilton and Rajaram, 2001) and the implicit category association test (Hamann, 1990; Srinivas and Roediger, 1990). Together, these patterns show that, while retrieval modes of explicit and implicit retrieval change accessibility in dramatic ways, the nature of the process demanded by the retrieval task (conceptual versus perceptual) can also change accessibility in a manner that is powerful and that can be orthogonal to the retrieval mode itself.

### 2.16.4.3 Remembering and Knowing

We now turn to a brief discussion of another type of distinction between two retrieval modes – remembering versus knowing one's past. Unlike the explicit–implicit distinction, where people are, respectively, either aware or not aware of the connection between the past and present, the remember–know distinction is made when people are aware of the connection. This distinction instead concerns the quality of retrieval experience that accompanies retrieval (Tulving, 1985). A person is said to engage in remembering if the retrieved memories are vivid and detailed. Remembering involves being able to think back to episodes and mentally reliving the past event, and in this way it is also said to involve mental time travel (Tulving, 2002). In brief, remembering is considered to be the purest measure of episodic memory. The experience of knowing is associated with semantic knowledge. Sometimes, retrieved information is associated with the past (unlike the case of implicit memory), but its rooting in the past lacks a sense of immediacy or detail such that one cannot tell when and where this information was encountered before. Despite having confidence in this type of memory, one experiences less personal connection and more of a generic sense about this information. In brief, Tulving proposed that the experience of knowing provided a measure of semantic memory. Tulving (1985) introduced the remember–know paradigm to enable quantitative measurements of these qualitative distinctions in retrieval.

The remember–know paradigm has been used widely to study the nature of retrieval experience and has produced both a large body of systematic findings and considerable debate (see Jacoby et al., 1997; Rajaram and Roediger, 1997; Gardiner and Conway, 1999; Rajaram, 1999; Gardiner and Richardson-Klavehn, 2000; Roediger et al., 2007, for reviews). For present purposes, we emphasize the dissociations and associations that systematically occur between these two distinct retrieval experiences. We have already discussed ways in which the levels-of-processing effect can vary as a function of encoding–retrieval interactions and explicit–implicit retrieval instructions. The presence of the levels of processing effect in explicit memory retrieval suggests that this effect should manifest itself in both remember and know judgments. However, the findings show that items studied for their meaning are given more remember judgments than items studied for their surface features, but this pattern is not observed for know judgments (Gardiner, 1988; Rajaram, 1993). Thus, retrieval can vary for the same set of encoding conditions even within the domain of explicit memory, once again emphasizing the important role that retrieval probes play in revealing the nature of memory.

In summary, we use the term retrieval mode to refer to distinct methods and experiences of retrieving information. Explicit retrieval refers to the conscious and intentional recall of previous experiences. In contrast, implicit retrieval refers to performance changes that are a result of prior experience but are unaccompanied by intentional or conscious recall of previous learning. Dissociations can occur between these two retrieval modes such that some factors (e.g., concrete/abstract words) can influence explicit memory but not implicit memory, while other factors (e.g., modality of presentation) can influence implicit memory but not explicit memory. Interestingly, the distinction between explicit and implicit memory retrieval is modified by the processing demands of these retrieval tasks such that dissociations can also occur *within* a particular mode of retrieval if the retrieval cues rely on different types of processes. As a result of this, *conceptual* implicit cues reveal the levels-of-processing differences but remain insensitive to modality changes, whereas *perceptual* implicit memory cues produce a reverse pattern of memory performance.

The notion of changes in the retrieval mode can also be applied to a distinction within explicit memory in terms of remembering and knowing – a distinction that is based on the quality of the information that is recalled. Remembering refers to recall that is accompanied by vivid details and a sense of mental time travel. In contrast, knowing refers to recall without specific details or a sense of when the information was encountered before. A dissociation also occurs between these two retrieval modes such that some factors (such as depth of processing) can influence remembering but not knowing. A variety of studies have also shown reverse dissociations and some associations as well between these two experiential modes of retrieval.

## 2.16.5 Repeated Retrieval

In previous sections, we focused on changes in the retrieval context – task differences, the match between encoding–retrieval interactions, and changes in the retrieval modes – to explore how retrieval processes affect detection of memory. We now review a class of retrieval phenomena that are quite different from the preceding ones but are equally important in revealing the nature of memory. These phenomena have to do with repeated attempts at thinking about a particular event. It is common experience to repeatedly try to recall something from the past that simply eludes us at a given moment. Are such efforts useful? In a research context, we might ask, do repeated attempts at recall improve memory performance? The brief answer to this question is yes. As Roediger and Karpicke (2006b) recently noted in their comprehensive review of research on testing effects,

> . . . testing not only measures knowledge, but also changes it, often greatly improving the retention of the tested knowledge. (Roediger and Karpicke, 2006b: 181)

Improvement in memory performance through repeated retrieval attempts can be understood by examining two related but distinct phenomena – hypermnesia and repeated testing. Hypermnesia refers to an improvement in the total amount of material recalled across repeated attempts, and it is usually obtained with free recall and not so often with other tasks. Repeated testing benefits occur when having taken a prior test – either recall or recognition – improves performance on a later test – again, either recall or recognition. We will review selective studies on both these phenomena as they reveal the importance of retrieval attempts.

Systematic efforts toward understanding the positive effects of repeated attempts – or hypermnesia – can be traced back to Ballard's (1913) and W. Brown's (1923) classic papers. Ballard proposed the concept of reminiscence and defined it as, "the remembering again of the forgotten without re-learning" (Ballard, 1913: 17). W. Brown introduced the phenomena of inter-test forgetting – the number of items that were recalled on the first attempt but not on the second – and inter-test recovery – the number of additional items recalled on the second attempt – to capture the effects of repeated recall on memory output. W. Brown's findings showed that repeated attempts at recalling a list of studied words (or recall of states) resulted both in inter-test forgetting and inter-test recovery, but there was an overall improvement in memory performance such that inter-test recovery exceeded inter-test forgetting across recall attempts. Erdelyi and Becker (1974) termed this reliable net gain across repeated attempts at recall as hypermnesia. Modern interest in research on hypermnesia can be traced back to the findings that Erdelyi and colleagues reported in the 1980s (see Erdelyi and Kleinbard, 1978; Erdelyi, 1984; Erdelyi et al., 1989).

Interestingly, for memory to improve with repeated testing, recall attempts do not have to occur necessarily in the form of consecutive and distinct recall tests. Roediger and Thorpe (1978) asked subjects to study 60 words or 60 pictures and attempt recall either in three successive recall tests (each lasting 7 min) or a single recall test that lasted 21 min. In both testing conditions, subjects were asked to draw a line after each minute of recall. Pictures produced greater hypermnesia than did words, a finding that seems to hold in other studies as well (see also Erdelyi and Becker, 1974; Payne, 1986), and this was true for three successive recalls as well as for one long recall that was equal in duration to three successive recalls. More relevant to the present point is the finding that recall increased over time in both retrieval conditions, and it did so at the same rate. An important implication of this finding for educational purposes is that having more time to retrieve information benefits performance even when the study efforts remain the same.

The presence of hypermnesia in Roediger and Thorpe's (1978) design shows that repeated retrieval effort over an extended period of time is the key to improving memory. But could memory improve simply by increasing the time that elapses between study and recall? This is, of course, a counterintuitive possibility because we expect delay to worsen memory, not improve it. However, in a standard repeated-testing design, the delay between study and a given recall test is confounded with the timing of multiple tests. That is, the second test comes much later in time than the first, and so on. Also, Shapiro and Erdelyi (1974) found that recall of studied pictures improved when the delay between study and recall was 5 min compared to when it was 30 s. The key to understanding this unexpected outcome may lie in the instructions subjects received during the 5-min delay; subjects were asked to covertly review the materials they had studied earlier. As Roediger and Payne (1982) argued, when subjects engaged in thinking about the study materials in Shapiro and Erdelyi's study, this act amounted to repeated retrieval practice and produced memory benefits despite the delay between study and recall.

To address this possibility, Roediger and Payne systematically examined the selective influence of delay between study and test and of the number of prior recall tests in a repeated testing design. In their study, all the subjects performed three recall tasks, but one group started the sequence after a short delay, the second group started the sequence at the time when the first group performed the second recall test, and the third group started the sequence at the time the first group performed the third recall test (**Table 4**). As the recall findings from this study show, recall was equivalent on the first recall test

**Table 4** Mean recall on the three successive tests for each delay condition

| *Condition* | *Items recalled* | | | | |
|---|---|---|---|---|---|
| Immediate | Test 1<br>25.6 | Test 2<br>27.9 | Test 3<br>30.1 | | |
| Short delay | | Test 1<br>25.1 | Test 2<br>27.5 | Test 3<br>29.8 | |
| Long delay | | | Test 1<br>25.6 | Test 2<br>28.9 | Test 3<br>31.3 |

Adapted from Roediger HL and Payne DG (1982) Hypermnesia: The role of repeated testing. *J. Exp. Psychol. Learn. Mem. Cogn.* 8(1): 66–72.

regardless of when the first test occurred (short delay, 25.6; intermediate delay, 25.1; long delay, 25.6). In contrast, recall increased during the same temporal window if the number of prior recall tests increased (the first test for the long-delay group, 25.6; the second test for the intermediate-delay group, 27.5; and the third test for the short-delay group, 30.1). Interestingly, many of these findings in hypermnesia studies have been secured with the study of pictures but not always with the study of words. We refer the reader to comprehensive reviews by Payne (1987) and Roediger and Challis (1989) for discussions on this and other complicating issues as well as for theoretical considerations in hypermnesia research. Regardless, these studies decisively point to the critical and specific role played by repeated attempts at retrieval in improving memory.

Repeated retrieval improves access to studied material in yet another way. Sometimes, the differential effects of different study methods that do not emerge on the first recall test are revealed on a later second test. For instance, in a study by Wheeler and Roediger (1992), subjects studied 60 pictures either presented one by one and accompanied with auditory presentation of the names or presented in the same manner visually but accompanied with an auditory presentation of a story. Shortly after completing a distractor task, subjects recalled the names of the pictures on one, two, or three successive tests. All the subjects returned 1 week later and also completed a final free-recall test. Their performance on this final test distinguished between the benefits of multiple retrievals for different study methods. Subjects' final recall was substantially higher for pictures that were embedded in a story than pictures that were presented without a story during study, and this difference became increasingly pronounced as the number of prior recall tests increased. Once again, we see the power of retrieval processes in that repeated retrieval can increase not only memory output when the study conditions remain the same; it can do so by bringing out the differential efficacy of study methods that might otherwise remain obscure.

As the preceding discussion shows, repeated retrieval clearly increases accessibility and produces improvements in memory. But in a discussion that emphasizes the importance of retrieval, it is important to ask what is more effective – repeated retrieval or repeated study? After all, a vast empirical literature in cognitive psychology shows that repeating information at study reliably improves recall and recognition (*see* the chapter by R. L. Greene in this volume on repetition and spacing effects; Chapter 2.06). There are many interesting phenomena associated with repetition at study, including the nearly ubiquitous demonstration that spaced repetition at study – that is, repeating items with one or more intervening trials in the study list – produces better memory compared to massed presentation – that is, repeating items twice or more in consecutive trials in the study list. Given the beneficial effects of repeated study, it is logical to ask how repeated retrieval fares in comparison. This question has been tested in many ways and from different theoretical as well as applied perspectives. Yet, the answer is impressively consistent. Repeated retrieval not only benefits memory, it does so to a greater extent than does repeated study. We recommend Roediger and Karpicke's (2006b) review that we earlier referenced for an in-depth discussion of different theoretical and empirical issues related to this broad question, and for the practical implications from this research for improving educational practices. Here, we will review a selection of studies that demonstrate this conclusion. In these studies, the focus is not on hypermnesia that arises when the same test is taken multiple times but on benefits of repeated testing where the successive tests are not necessarily identical, but having taken the prior tests nevertheless improves performance on the later tests.

As early as the first quarter of the twentieth century, two studies demonstrated many of the key findings from repeated-testing designs. In one study, Gates (1917) varied the amount of time given to subjects for only studying versus for recalling while being able to refresh memory for the forgotten material. On a final (serial) recall test of the studied material (nonsense syllables or biographies), Gates found that spending more time on recall with opportunities to refresh the forgotten information produced better final recall than more time devoted only for study – provided that a certain, minimum amount of time was first spent for study in the former condition (see also Thompson et al., 1978).

In another study, Spitzer (1939) found that two attempts at retrieval improved memory on a multiple-choice recognition memory test. Furthermore, the sooner the first test was administered, the less was the forgetting and the higher was the performance on a later second test. The inoculating effects of the first test, and of its timing, have received considerable attention in the repeated-testing literature. While the inoculating effects of the first test on later memory seem secure (Wheeler and Roediger, 1992), the specifics concerning the optimal timings of multiple tests continue to be investigated (Landauer and Bjork, 1978; Balota et al., 2006, 2007; Logan and Balota, in press).

The early intimations of a relative advantage of increased testing over increased studying in the studies by Gates (1917) and Spitzer (1939) have been systematically tested from various perspectives in the modern literature and have produced a very nice body of data. A key factor in predicting the relative advantage of repeated study versus repeated retrieval concerns the delay between study and the final memory test. In a seminal study, Tulving (1967) used a comprehensive design that included comparisons of various study–test schedules for a total of 24 trials each and had subjects study a total of 36 words – alternating study and test (STST, STST, and so on), three study and one test (SSST, SSST, and so on), and one study and three tests (STTT, STTT, and so on.) Also critical for present purposes, subjects were given 1 s per item to study and an equivalent total of time for test (so, subjects received 36 s to recall all the studied items.) The results showed that recall performance was comparable over the 24 trials across the three different study-test schedules. In other words, repeated testing did not improve memory over repeated study.

Tulving's findings were surprising in light of the general conclusion we have already stated, but these findings were replicated by others (e.g., Lachman and Laughery, 1968; Rosner, 1970; Birnbaum and Eichner, 1971; Donaldson, 1971). Also, these findings make sense if we consider them in light of Roediger and Thorpe's (1978) findings we discussed earlier; recall improves as subjects receive additional time to do the task. However, in Tulving's experiment subjects were given only 36 s to recall 36 words. Even if the words had been perfectly learned, this is a very short time period with which to recall them. Initial support for this possibility was found in a study where subjects either studied a list of 40 words four times or studied it once and recalled it three times (Hogan and Kintsch, 1971; see also Thompson et al., 1978). In a final recall test conducted 2 days later, prior training with multiple tests produced 5% better recall than prior training with multiple study.

Roediger and Karpicke (2006a, Experiment 2) recently published a study using educational materials that provides an impressive resolution to the question concerning the relative importance of repeated study versus repeated tests. Subjects studied prose passages on scientific topics and were tested on a recall test that was similar to essays in its format. In one condition, subjects studied the passage four times (SSSS). In a second condition, subjects studied the passages three times and were tested once (SSST), and in the final condition, subjects studied the passages once and were tested three consecutive times (STTT). Subjects also took a final recall test either 5 min or 1 week after this learning sequence. As can be seen in **Figure 3**, more idea units were recalled following repeated study if the final recall test occurred after a short delay of 5 min. But the final recall performance was better after repeated testing if

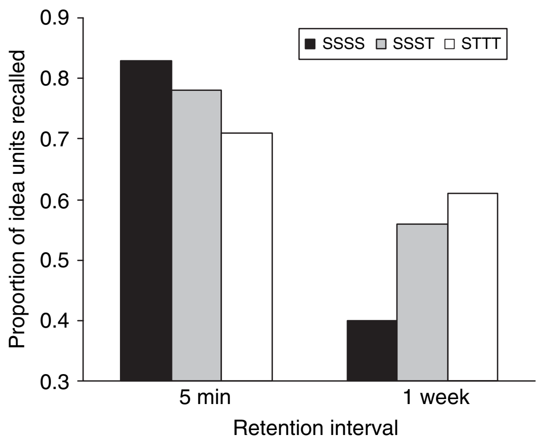


**Figure 3** Mean proportion of idea units recalled on the final test after a 5-min or 1-week retention interval as a function of learning condition (SSSS, SSST, or STTT). The labels for the learning conditions indicate the order of study (S) and test (T) periods. Adapted from Experiment 2 in Roediger HL III and Karpicke JD (2006a) Test-enhanced learning: Taking memory tests improves long-term retention. *Psychol. Sci.* 17(3): 249–255, with permission from Blackwell Publishing.

the final test occurred after a long delay of 1 week. In summary, these findings pinpoint the key conditions that are responsible for when study and retrieval repetitions can produce differential benefits in memory; repeated study improves memory in the short term, but repeated testing produces improvements in the long term. This long-term advantage of repeated testing over repeated study seems secure because it has been shown to also occur with word lists (Wheeler et al., 2003).

A general explanation for why repeated retrieval benefits long-term retention more than repeated study harkens back to the principle of transfer-appropriate processing we discussed in earlier sections on encoding–retrieval interactions and retrieval mode (Morris et al., 1977; Roediger et al., 1989). Roediger and Karpicke (2006b) recently noted that one reason for the superiority of repeated retrieval is that the same processes are engaged when people retrieve information again, whereas, as McDaniel (2007) has argued, different processes are often engaged across learning and testing situations. The match in processes in the former condition illustrates the operation of transfer-appropriate processing.

Another explanation of the benefit of repeated testing is that initial testing results in the creation of multiple retrieval routes to the to-be-remembered item, thus making recall more likely at a later test. In a study by McDaniel and Masson (1985), subjects were given either a phonemic or a semantic encoding task followed by a cued-recall test with either semantic or phonemic cues. Thus, half of the subjects received the same type of information at encoding and the first test, and half of the subjects received a different type of information at encoding than at the first test. Later, subjects were able to recall more information on a second test when the cues from the first test had not matched the original encoding. This finding is consistent with the idea that the initial test improves recall on a later test if it is able to produce an elaboration of the existing memory trace by increasing the variability of the encoded information (see also McDaniel et al., 1989). From a retrieval point of view, this means not only that retrieval is changing the existing memory representation, but that varied changes make subsequent retrieval more and more likely to occur.

Roediger and Karpicke (2006b) have reviewed a sizeable literature that points to yet another related but distinct basis for benefits from repeated retrieval, namely the process of generation. Briefly, just as the generation processes at encoding improve memory such that items generated from semantic cues are later recalled and recognized more often than items that were simply read, generation of studied items during first recall improves performance on a following test (see Jacoby, 1978; Bjork and Bjork, 1992; Bjork, 1994, 1999; Roediger and Karpicke, 2006a). Consistent with this idea, a prior recall test that requires generation of studied information (such as providing short answers) improves performance on later recall (short answers) as well as recognition (multiple-choice format), whereas a prior recognition test (that does not require generation because the studied items are presented again) does not produce comparable benefits on later tests (Kang et al., 2007). Recent work (McDaniel et al., 2007) has also demonstrated this effect in a college course. In this study a benefit was found for short-answer quizzes (a recall test) over additional study but not for multiple-choice quizzes (a recognition test) over additional study on a final exam. This is particularly impressive given not only the variability of additional studying and motivation of the students within the class, but also the fact that the quizzes were administered up to 5 weeks prior to the final exam. Findings such as these reveal the specificity of effects that prior retrieval produces on later retrieval and point to the underlying processes that mediate such patterns.

In conclusion, testing – or retrieval – not only has a powerful influence on long-term retention but is also an effective learning device with important educational implications. The judicious use of testing in educational settings should benefit students' performance. This goal is embodied in recent cognitive research that aims to identify optimal retrieval practices for improving retention and academic performance. We refer the reader to M. A. McDaniel's chapter on 'Education and Learning' in this volume (*see* Chapter 2.43) for an in-depth discussion of these important issues.

## 2.16.6 Retrieval in a Social Context

For decades now, experimental studies on memory have typically focused on the individual, and the study of retrieval processes has been no exception. But just as we retrieve the past not just once but often repeatedly, we also retrieve the past not just alone but often in collaboration with others. People recall the past in dyads (e.g., friends and couples), triads (e.g., friends, colleagues), or in larger groups. It was only around the mid- to late 1990s that research on the effects of social context on memory started to gain momentum. We review some of the core findings from this area of research as relevant to the process of retrieval here and refer the readers to scholarly reviews by Weldon (2001) for the historical antecedents and the emerging research on social processes in memory, and by M. Ross (*see* Chapter 2.47) and J. V. Wertsch (*see* Chapter 2.48) in this volume on the nature of social memory processes and collective memory, respectively.

Both the early neglect of group processes and the recent focus on group processes make sense on theoretical and empirical grounds, because assessment of how social processes influence retrieval first requires a clear understanding of how individual memory processes work in isolation. Now that a substantial body of evidence and major theoretical frameworks are in place on the nature of individual memory, researchers have the necessary empirical and theoretical bases against which the social influences on individual memory can be measured. Similarly, researchers can also test for potential similarities and differences between individual memory and group memory processes.

We first focus on group memory because retrieval processes appear to play a central role in mediating group memory effects. Studies that report group retrieval – or collaborative memory – effects typically compare collaborating groups to nominal (or control) groups. In collaborative groups, members collaborate during retrieval. In nominal groups the nonredundant responses of an equal number of individuals who worked alone are pooled together (Basden et al., 1997; Weldon and Bellinger, 1997). Collaboration in the experimental group is instantiated by asking subjects to contribute their retrieved responses in any order or in a turn-taking order. Results do not seem to change as a function of the particular procedure used for collaboration (Basden et al., 1997; Weldon and Bellinger, 1997; Weldon et al., 2000; Wright and Klumpp, 2004).

The central finding in group retrieval studies turns out to be counterintuitive. Collaborating groups recall significantly fewer studied items than nominal groups (Basden et al. 1997; Weldon and Bellinger, 1997), a phenomenon that Weldon and Bellinger (1997) call collaborative inhibition. In Weldon and Bellinger's experiment, participants encoded a list of words alone. Later, they were asked to recall the information either individually or in a collaborative group of three individuals. When the participants recalled individually, a nominal group score was created that consisted of counting up all the nonredundant answers of three individuals. The results indicated that, while collaborative groups recalled more than the average individual, the nonredundant responses of three individuals recalling alone (i.e., nominal groups) exceeded collaborative group performance.

Collaborative inhibition appears to be largely a retrieval phenomenon, as this effect is reliably observed when the encoding conditions are held constant across the nominal and collaborative groups. The retrieval basis of this effect is further supported by the proposal that collaborative inhibition is similar to another well-known retrieval phenomenon, namely, the part-list cuing inhibition effect (Slamecka, 1968; Basden et al., 1977; Roediger and Neely, 1982; Basden and Basden, 1995). The part-list cuing inhibition refers to yet another counterintuitive phenomenon in memory; when subjects are presented with a partial list of studied words during recall and are asked to recall the remaining studied words, their recall is poorer for the remaining subset compared to a condition where none of the studied items are provided during recall. Thus, having access to a part of the studied lists inhibits the recall of the remaining words. The locus of this effect appears to be at retrieval because recall for the remaining subset improves on a later trial if the partial list is no longer provided. Thus, the dip in recall during the first trial turns out to be temporary and does not reflect poorer encoding or storage in the part-list condition. This finding then begs the question – why do partial lists inhibit recall? Evidence shows that individuals develop their own idiosyncratic organization of the studied material and use it during recall (Tulving, 1962; Roenker et al., 1971; Rundus, 1971). The presence of a subset of items during recall disrupts such organizational and retrieval strategies and leads to suboptimal recall performance (Basden and Basden, 1995).

B. H. Basden and colleagues extended the logic of retrieval disruption to the collaboration situation and tested the idea that collaborative inhibition observed in group memory is similar to the part-list cuing inhibition effect in individual memory. The logic behind this theoretical extension goes like this. Recall of a given member is reduced in a collaborative group because responses produced by other group members serve as part-list cues and disrupt the idiosyncratic retrieval strategies on which each individual member relies during group recall. Such retrieval disruption – resulting from the input of other group members – reduces the individual contributions from each member and leads to lowered group recall.

B. H. Basden et al. (1997) reported evidence that supports the retrieval disruption hypothesis. In this series of experiments, B. H. Basden and colleagues also reported the same pattern of results as Weldon and Bellinger (1997), showing that nominal recall was greater than collaborative recall. However, they also showed that this effect was mediated by the extent to which collaboration disrupts the individual's organizational structure. For example, in their first study, participants were given one of two types of encoding tasks. Some participants were asked to learn many (15) instances of a few (6) categories. Other participants were asked to learn few (6) instances of many (15) categories. D. R. Basden and Draper (1973) had previously argued that within-category organization is more likely to occur with large categories. As a result, each individual's retrieval strategy should be at more variance from another individual's retrieval strategy when the categories are large. If collaborative inhibition is due to retrieval disruption, there should be greater collaborative inhibition for participants who studied large categories (15 instances of 6 categories) than for participants who studied small categories (6 instances of 15 categories). Consistent with this hypothesis, the magnitude of collaborative inhibition varied as a function of list structure. In fact, collaborative inhibition was found only for participants who studied large categories and not for participants who studied small categories.

The collaborative inhibition effect in group retrieval and the part-list cuing inhibition effect in individual retrieval are related in yet another interesting way. As we have described, both phenomena are said to occur because of retrieval disruption during retrieval. It turns out that in both cases retrieval disruption does not impair individual memory beyond the conditions where it operates. As we noted earlier, in the case of part-list cuing inhibition, there is evidence that, if the part-list cues are removed during subsequent individual recall, subjects elicit previously blocked studied words (Basden et al., 1977). Similarly, after the completion of the group retrieval session, if each group member individually recalls studied items, the 'lost' items during collaboration resurface in later individual recall (Finlay et al., 2000; see also Weldon and Bellinger, 1997). These interesting parallels suggest that group retrieval can be sensitive to the same cognitive mechanisms that mediate individual retrieval.

In an earlier section on task differences, we discussed the critical role retrieval cues play in determining the accessibility of studied information. Initial evidence from studies on collaborative memory suggests retrieval cues also modulate the key finding on which we have focused here – collaborative inhibition in group retrieval. Collaborative inhibition typically occurs when a collaborative group engages in free recall (Basden et al., 1997; Weldon and Bellinger, 1997). This outcome is consistent with the retrieval disruption account because, as we have noted, free recall relies heavily on the internal organization and strategies of each participant, and the disruption of this strategy lowers each member's contribution to the group product.

This logic predicts that, if more cues are provided as external aids during retrieval, each participant group member would need to rely much less on internal resources. As a result, disruption is less likely to be a factor during the process of collaboration when retrieval cues are present. Current evidence supports this argument. While collaborative inhibition consistently occurs in free recall, this effect disappears in a paired-associate recall task that provides partial study cues, and even reverses in a recognition memory task that recapitulates the entire study item. Finlay et al. (2000) reported a study in which subjects studied pairs of weakly related words. At test, subjects received the first word of the studied pair and recalled the second pair either individually or in pairs. Nominal dyad performance (nonredundant, pooled recall of two individuals who worked alone) did not differ from that of the collaborating dyads even though the typical collaborative inhibition effect occurred with the free-recall task.

Clark and colleagues (2000) used the recognition memory task in their study on collaborative memory with the aim of elucidating the nature of the collaboration process from a different perspective. But their findings are interesting in the present context for yet another, related, reason – the effects of maximal retrieval cues on mediating collaborative memory. Subjects studied a list of unrelated words and were later tested on a recognition memory task that consisted of an intermixed list of studied and nonstudied words. These researchers assessed the performance of three-member collaborative groups against three measures derived from the nominal groups of same size – the best group member, the majority vote, and the average of the group. In all three comparisons, the recognition performance of the collaborative groups exceeded that of the nominal groups. In other words, Clark et al. reported that there was a collaborative facilitation effect in recognition memory.

We have focused on group retrieval to discuss the role of retrieval in assessing memory in a social context. We close this section by briefly describing evidence that has just started to emerge on how social processes can affect individual retrieval. As we noted earlier, the disruptive effects of collaboration are temporary, and later individual recall shows recovery of studied items that were not produced during collaboration.

In a study from our own lab, we examined this effect in recognition. We presented subjects with a list of unrelated words to study and later gave a recognition task in which we assessed effects of collaborative discussion on individual memory (Rajaram and Pereira-Pasarin, 2007). We found that collaborative discussion just prior to making individual recognition responses led to more accurate performance (in both d′ and hits–false alarm measures) than in a retrieval condition that required no prior collaboration. The beneficial effects of collaboration here are impressive because collaboration can potentially affect individual recognition in a negative or a positive direction. It can increase an individual's propensity to go along with the group's input regardless of whether or not it is correct. Individuals can accept nonstudied items as studied, reject studied items, or do both, thereby producing lower memory accuracy. Or, individual subjects can reject more nonstudied items or accept more studied items, or do both, thereby increasing memory accuracy. Yet, group input in our study enhanced individual recognition, and this advantage persisted up to 1 week (see **Figure 4**). As we discuss in a later section titled

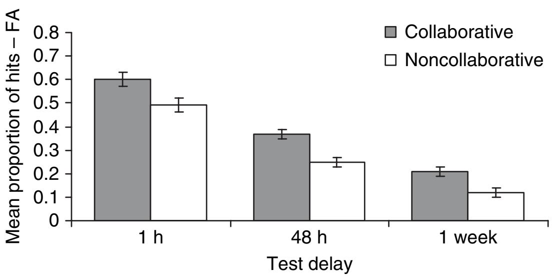


**Figure 4** Mean proportion of hits minus false alarms (FA) as a function of collaborative and noncollaborative conditions and retention interval. Adapted from Experiment 2 in Rajaram S and Pereira-Pasarin L (2007) Collaboration can improve individual recognition memory: Evidence from immediate and delayed tests. *Psychon. Bull. Rev.* 14: 95–100.

'Retrieval errors and other retrieval phenomena,' such benefits do not always occur, because other researchers have shown that input from other group members can sometimes increase memory errors. Regardless, this cluster of findings shows that encoding in and of itself does not determine how much or what an individual will ultimately remember. Retrieval processes – either inherent in the individual or modified by social input – play a large role in determining the final memory output.

As Gardner (1985) noted, researchers have tended to set aside social, emotional, and cultural processes in the pursuit of understanding cognition. In other words, researchers have typically viewed social, emotional, and cultural processes as contextual factors whose influences need to be controlled for rather than as key components in understanding cognition. But memory – or more specifically, retrieval – is usually a social process (Weldon, 2001). Not only do people often recall with others (as discussed in this section, and to some extent also in a later section on retrieval errors), but how the recalled information is interpreted is often a function of the person's sociocultural environment. Theories of memory that are based only on the individual are therefore incomplete. The initial evidence (briefly presented earlier; *see* Chapter 2.47) provides initial support for these conclusions and also suggests that future research should focus on social processes of memory as a factor rather than a confounding variable.

To summarize, collaborative inhibition is the counterintuitive finding that collaborative groups are able to recall less information than the pooled nonredundant responses of nominal groups of equal size. This is theorized to be a retrieval effect similar to the part-list cuing effect. Retrieval disruption (created by the recall products of other group members in the case of collaborative retrieval) disrupts individuals' idiosyncratic retrieval strategies and causes poorer overall memory performance. However, this disruption does not seem to impair subsequent individual memory, and in some cases (for instance, as with recognition memory) may actually enhance individual memory.

## 2.16.7 Retrieval Errors and Other Retrieval Phenomena

Earlier, we reviewed research that shows that repeated retrieval improves memory. As Bjork (1975) noted, retrieval is a memory modifier. Interestingly, the act of retrieval can also reduce memory accuracy. People recall emotional, significant, or entertaining events from their lives often, and it is all too common to embellish the events from one telling to the next or from one audience to another. Bartlett's (1932) classic study is often cited to illustrate how memory output can change from one recall to the next. In this study, people were asked to read a Native American story called 'The War of the Ghosts.' Importantly, the significance of many details in this story was not apparent to people of different cultural backgrounds. The more times that people were asked to retell the story, the more the stories became distorted such that subjects omitted unfamiliar details and inserted materials to make the story consistent with their schemas. These dramatic changes across repeated retrievals have since been replicated in a study by Bergman and Roediger (1999).

Bartlett's (1932) study and Bergman and Roediger's (1999) critical replication show that individuals modify story output even without any intervention from outside sources. It is easy to imagine then that the social situations individuals encounter can change the contents of what individuals might retrieve from one occasion to the next. For example, social situations often dictate whether a story should be told in an accurate or entertaining fashion. In a study by Dudukovic et al. (2004) participants were asked to either retell a story with a goal to be accurate, or with a goal to be entertaining. While the participants did not differ on a later recognition test, they did differ on a later recall test. The participants who had originally told the story accurately recalled more information with less exaggeration than the participants who had originally told the story for entertainment. Thus, the way that we recount information to others influences the way that information is later recalled. As we will describe next, retrieval errors can also creep into individual performance when others provide input during retrieval.

In a previous section on retrieval in a social context, we discussed evidence that shows positive influences of input from others. But individuals also make more retrieval errors under certain conditions if they previously received erroneous input from others. In a study that assessed the effects of social contagion, Roediger et al. (2001) presented subjects with everyday scenes (e.g., a kitchen) during the study phase. Later, subjects recalled the scenes along with a confederate who inserted related but nonstudied items during recall (e.g., toaster). On a final test where subjects engaged in recall alone, they falsely recalled related but nonstudied items more often if they had been inserted by a confederate in the earlier recall phase than if no mention of them had been made.

Basden et al. (2002) reported similar effects of social input in a study where they presented semantically related 'DRM' (Deese-Roediger-McDermott) lists during study and constructed a perceived group-recall situation with the use of interconnected computers. DRM lists consist of thematically related words such as 'dream,' 'bed,' 'night,' etc., where a critical word such as 'sleep' is missing. In individual memory studies, subjects erroneously recall these critical nonpresented words at levels as high as true recall and also give 'remember' responses indicating vivid memory for having seen them before (Roediger and McDermott, 1995). In Basden et al.'s study, subjects engaged in perceived group recall followed by individual recall. During perceived group recall, the subjects were led to believe that they viewed the responses of other group members on the computer screen during recall but in fact the generated responses were controlled by the experimenter. In one condition of perceived group recall, subjects saw the critical, nonpresented lures, and in another condition these items were not included in the supposed responses from other members. Subjects included more erroneous responses in their final individual recall protocols if they had previously participated in one of the two perceived group-recall phases than if they had not participated in the perceived group-recall phase. In this way, individual retrieval can be socially influenced. The process of collaboration can lead to individual retrieval benefits as discussed in the previous section but also to retrieval errors, as these studies show (also see Basden et al., 2000, 2002; Reysen, 2005, for related findings).

Another topic of considerable interest in memory retrieval focuses on the subjects' ability to identify the source of information they recall – a phenomenon called reality monitoring (Johnson and Raye, 1981) The general approach here is to ask subjects whether the item they recalled (or recognized) was presented to them (i.e., the item originated from perception) or was internally generated (i.e., the item was something they imagined or dreamed). According to this framework (e.g., Johnson, 1991; Johnson et al., 1993), people do not explicitly tag memories with source information. Rather, they typically make source attributions based on a generalized evaluation of whether a memory's qualities match expectations. These judgments capitalize on the average differences of the characteristic qualities of memories from different sources. For instance, perceived events tend to include more information about perceptual, temporal, spatial, and affective characteristics and less information about cognitive processes than imagined events. A judgment of 'perceived' rather than 'imagined' should therefore be given if the evaluation of a memory's qualities results in a great deal of information about perceptual and spatial details, accompanied by little information about the cognitive processes that took place during encoding. Attributing a memory to the source for which that memory's qualities are most characteristic maximizes the odds of accurately judging the memory's source. Reality-monitoring failures occur when people falsely claim either that something was perceived when it was actually internally generated or that something was internally generated when it was actually perceived. A detailed review of this topic can be found in a chapter on source monitoring by S. Lindsay (*see* Chapter 2.19) in this volume.

These processes in reality monitoring constitute yet another form of retrieval, one that is characterized by metamemory judgments, because subjects make judgments about information retrieved from memory. In an earlier section on retrieval mode, we described remember and know judgments, which can also be considered metamemory judgments because subjects report the quality of memory for the information they retrieve (see Rajaram and Roediger, 1997; Rajaram, 1999; Roediger et al., 2007). There are also other well-known metamemory judgments such as feelings of knowing (see Koriat, 1995) and the tip-of-the-tongue state (see Brown, 1991; Schwartz et al., 2000) that researchers study to find out subjects' sense of what they can retrieve even when recall does not succeed. These judgments reveal interesting – metacognitive – aspects of the retrieval process as subjects make judgments about the likelihood of retrieval under certain circumstances. In the feeling-of-knowing state (see Koriat, 1995) subjects can reliably report whether they can recognize an item on a multiple-choice test even though they were unable to recall that item, and in the tip-of-the-tongue state, people can reliably indicate whether or not the information they are trying to retrieve is on the tip of their tongue and could be retrieved. We recommend chapters by A. Koriat on control processes in remembering (*see* Chapter 2.18) and by A. S. Brown on the tip-of-the-tongue states (*see* Chapter 2.22) for detailed discussions of these topics.

In conclusion, the ways in which retrieval conditions are arranged to a large extent determine how much memory accessibility can improve. But in many situations, retrieval can also act as a memory modifier and can do so in systematic ways. Such situations can lead to systematic errors in retrieval, as revealed by the DRM effect. Furthermore, when recalling information, people are motivated not only to present a coherent story, but also to tell the story with a particular purpose (for example, to be entertaining). Both of these motivations can serve to lower overall memory accuracy. Retrieval errors can also be the result of social influences (believing that you saw something that someone else endorsed seeing), or reality monitoring errors (believing that you saw something that you only imagined seeing). Finally, many meta-memory processes such as the tip-of-the-tongue phenomenon also modulate the success of retrieval.

## 2.16.8 Concluding Comments

As we noted in the introduction, much of memory research has been guided by a focus on three putative components – encoding, storage, and retrieval. But from the perspective of the rememberer, it is the act of retrieval that constitutes memory. In this chapter, we have taken this perspective to explore various phenomena in memory research that tell us something important about the process of retrieval and ways in which this process enables access to what we have learned. The phenomena and findings reviewed in this chapter point to the unique role that retrieval processes play in modifying the effects of different encoding processes. Above all, these findings show that, without a proper understanding of the nature and power of retrieval, our understanding of how memory works is not only incomplete but also flawed.

## References

Ballard PB (1913) Obliviscence and reminiscence. *Br. J. Psychol.* 1(II): 82.

Balota DA, Duchek JM, Sergent-Marshall SD, and Roediger HL III (2006) Does expanded retrieval produce benefits over equal-interval spacing? Explorations of spacing effects in healthy aging and early stage Alzheimer's disease. *Psychol. Aging* 21(1): 19–31.

Balota DA, Duchek JM, and Logan JM (2007) Is expanded retrieval practice a superior form of spaced retrieval? A critical review of the extant literature. In: Nairne JS (ed.)

*The Foundation of Remembering: Essays in Honor of Henry L. Roediger, III*, pp. 83–105. New York: Psychology Press.
Bartlett FC (1932) *Remembering: A Study in Experimental and Social Psychology*. Oxford, England: Macmillan.
Basden BH, Basden DR, Bryner S, and Thomas RL III (1997) A comparison of group and individual remembering: Does collaboration disrupt retrieval strategies? *J. Exp. Psychol. Learn. Mem. Cogn.* 23(5): 1176–1191.
Basden BH, Basden DR, and Henry S (2000) Costs and benefits of collaborative remembering. *Appl. Cogn. Psychol.* 14: 497–507.
Basden BH, Reysen MB, and Basden DR (2002) Transmitting false memories in social groups. *Am. J. Psychol.* 115(2): 211–231.
Basden DR and Basden BH (1995) Some tests of the strategy disruption interpretation of part-list cuing inhibition. *J. Exp. Psychol. Learn. Mem. Cogn.* 21(6): 1656–1669.
Basden DR, Basden BH, and Galloway BC (1977) Inhibition with part-list cuing: Some tests of the item strength hypothesis. *J. Exp. Psychol. Hum. Learn. Mem.* 3(1): 100–108.
Basden DR and Draper JS (1973) Effect of cueing with list members in free recall as a function of number of categories, taxonomic frequency, and presentation order. *Can. J. Psychol.* 27(3): 327–333.
Beck RC and McBee W (1995) Mood-dependent memory for generated and repeated words: Replication and extension. *Cogn. Emot.* 9(4): 289–307.
Bergman ET and Roediger HL III (1999) Can Bartlett's repeated reproduction experiments be replicated? *Mem. Cognit.* 27(6): 937–947.
Birnbaum IM and Eichner JT (1971) Study versus test trials and long-term retention in free-recall learning. *J. Verbal Learn. Verbal Behav.* 10(5): 516–521.
Bjork RA (1975) Retrieval as a memory modifier. In: Solso R (ed.) *Information Processing and Cognition: The Loyola Symposium*, pp. 123–144. Hillsdale, NJ: Erlbaum.
Bjork RA (1994) Memory and metamemory considerations in the training of human beings. In: Metcalfe J and Shimamura AP (eds.) *Metacognition: Knowing about Knowing*, pp. 185–205. Cambridge, MA: The MIT Press.
Bjork RA (1999) Assessing our own competence: Heuristics and illusions. In: Gopher D and Koriat A (eds.) *Attention and Performance XVII: Cognitive Regulation of Performance: Interaction of Theory and Application*, pp. 435–459. Cambridge, MA: The MIT Press.
Bjork RA and Bjork EL (1992) A new theory of disuse and an old theory of stimulus fluctuation. In: Healy AF, Kosslyn SM, and Shiffrin RM (eds.) *Essays in Honor of William K. Estes, Vol. 2: From Learning Processes to Cognitive Processes*, pp. 35–67. Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
Blaney PH (1986) Affect and memory: A review. *Psychol. Bull.* 99(2): 229–246.
Blaxton TA (1989) Investing dissociations among memory measures: Support for a transfer-appropriate processing framework. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 657–668.
Bower GH (1981) Mood and memory. *Am. Psychol.* 36(2): 129–148.
Bower GH and Mayer JD (1989) In search of mood-dependent retrieval. *J. Soc. Behav. Personal.* 4(2): 121–156.
Bower GH, Monteiro KP, and Gilligan SG (1978) Emotional mood as a context for learning and recall. *J. Verbal Learn. Verbal Behav.* 17(5): 573–585.
Brown AS (1991) A review of the tip-of-the-tongue experience. *Psychol. Bull.* 109(2): 204–223.
Brown W (1923) To what extent is memory measured by a single recall? *J. Exp. Psychol.* 6(5): 377–382.
Clark SE, Hori A, Putnam A, and Martin TP (2000) Group collaboration in recognition memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 26(6): 1578–1588.
Craik FI and Lockhart RS (1972) Levels of processing: A framework for memory research. *J. Verbal Learn. Verbal Behav.* 11(6): 671–684.
Craik FI and Tulving E (1975) Depth of processing and the retention of words in episodic memory. *J. Exp. Psychol. Gen.* 104(3): 268–294.
Donaldson W (1971) Output effects in multitrial free recall. *J. Verbal Learn. Verbal Behav.* 10(5): 577–585.
Dudukovic NM, Marsh EJ, and Tversky B (2004) Telling a story or telling it straight: The effects of entertaining versus accurate retellings on memory. *Appl. Cogn. Psychol.* 18(2): 125–143.
Eich E (1985) Context, memory, and integrated item/context imagery. *J. Exp. Psychol. Learn. Mem. Cogn.* 11(4): 764–770.
Eich E (1995a) Mood as a mediator of place dependent memory. *J. Exp. Psychol. Gen.* 124(3): 293–308.
Eich E (1995b) Searching for mood dependent memory. *Psychol. Sci.* 6(2): 67–75.
Eich E, Macaulay D, and Ryan L (1994) Mood dependent memory for events of the personal past. *J. Exp. Psychol. Gen.* 123(2): 201–215.
Eich E and Metcalfe J (1989) Mood dependent memory for internal versus external events. *J. Exp. Psychol. Learn. Mem. Cogn.* 15(3): 443–455.
Eich JE (1980) The cue-dependent nature of state-dependent retrieval. *Mem. Cognit.* 8(2): 157–173.
Eich JE, Weingartner H, Stillman RC, and Gillin JC (1975) State-dependent accessibility of retrieval cues in the retention of a categorized list. *J. Verbal Learn. Verbal Behav.* 14(4): 408–417.
Erdelyi MH (1984) The recovery of unconscious (inaccessible) memories: Laboratory studies of hypermnesia. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 18, pp. 95–127. New York: Academic Press.
Erdelyi MH and Becker J (1974) Hypermnesia for pictures: Incremental memory for pictures but not words in multiple recall trials. *Cogn. Psychol.* 6(1): 159–171.
Erdelyi MH, Finks J, and Feigin-Pfau MB (1989) The effect of response bias on recall performance, with some observations on processing bias. *J. Exp. Psychol. Gen.* 118(3): 245–254.
Erdelyi MH and Kleinbard J (1978) Has Ebbinghaus decayed with time? The growth of recall (hypermnesia) over days. *J. Exp. Psychol. Hum. Learn. Mem.* 4(4): 275–289.
Fernandez A and Glenberg AM (1985) Changing environmental context does not reliably affect memory. *Mem. Cognit.* 13(4): 333–345.
Finlay F, Hitch GJ, and Meudell PR (2000) Mutual inhibition in collaborative recall: Evidence for a retrieval-based account. *J. Exp. Psychol. Learn. Mem. Cogn.* 26(6): 1556–1567.
Gardiner JM (1988) Functional aspects of recollective experience. *Mem. Cognit.* 16(4): 309–313.
Gardiner JM and Conway MA (1999) Levels of awareness and varieties of experience. In: Challis BH and Velichkovsky BM (eds.) *Stratification in Cognition and Consciousness*, pp. 237–254. Amsterdam: John Benjamins Publishing Company.
Gardiner JM and Richardson-Klavehn A (2000) Remembering and knowing. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 229–244. New York: Oxford University Press.
Gardner H (1985) *The Mind's New Science: A History of the Cognitive Revolution*. New York: Basic Books.
Gates AI (1917) Recitation as a factor in memorizing. *Arch. Psychol.* 6(40).
Godden DR and Baddeley AD (1975) Context-dependent memory in two natural environments: On land and underwater. *Br. J. Psychol.* 66(3): 325–331.
Graf P and Mandler G (1984) Activation makes words more accessible, but not necessarily more retrievable. *J. Verbal Learn. Verbal Behav.* 23(5): 553–568.

Graf P and Schacter DL (1985) Implicit and explicit memory for new associations in normal and amnesic subjects. *J. Exp. Psychol. Learn. Mem. Cogn.* 11(3): 501–518.

Hamann SB (1990) Level-of-processing effects in conceptually driven implicit tasks. *J. Exp. Psychol. Learn. Mem. Cognit.* 16: 970–977.

Hamilton M and Rajaram S (2001) The concreteness effect in implicit and explicit memory tests. *J. Mem. Lang.* 44(1): 96–117.

Hamilton M and Rajaram S (2003) States of awareness across multiple memory tasks: Obtaining a 'pure' measure of conscious recollection. *Acta Psychol.* 112(1): 43–69.

Hogan RM and Kintsch W (1971) Differential effects of study and test trials on long-term recognition and recall. *J. Verbal Learn. Verbal Behav.* 10(5): 562–567.

Jacoby LL (1978) On interpreting the effects of repetition: Solving a problem versus remembering a solution. *J. Verbal Learn. Verbal Behav.* 17(6): 649–667.

Jacoby LL and Dallas M (1981) On the relationship between autobiographical memory and perceptual learning. *J. Exp. Psychol. Gen.* 110(3): 306–340.

Jacoby LL, Yonelinas AP, and Jennings JM (1997) The relation between conscious and unconscious (automatic) influences: A declaration of independence. In: Cohen JD and Schooler JW (eds.) *Scientific Approaches to Consciousness*, pp. 13–47. Hillsdale, NJ: Lawrence Erlbaum Associates.

Johnson MK (1991) Reflection, reality monitoring, and the self. In: Kunzendorf RG (ed.) *Mental Imagery*, pp. 3–16. New York: Plenum Press.

Johnson MK, Hashtroudi S, and Lindsay DS (1993) Source monitoring. *Psychol. Bull.* 114(1): 3–28.

Johnson MK and Raye CL (1981) Reality monitoring. *Psychol. Rev.* 88(1): 67–85.

Kang SHK, McDermott KB, and Roediger HL (2007) Test format and corrective feedback modify the effect of testing on memory retention. *Eur. J. Cogn. Psychol.* 19: 528–558.

Kirsner K, Milech D, and Standen P (1983) Common and modality-specific processes in the mental lexicon. *Mem. Cognit.* 11: 621–630.

Kohler W (1947) *Gestalt Psychology,* 2nd edn. Oxford: Liveright.

Kolers PA and Roediger HL (1984) Procedures or mind. *J. Verbal Learn. Verbal Behav.* 23: 425–449.

Koriat A (1995) Dissociating knowing and the feeling of knowing: Further evidence for the accessibility model. *J. Exp. Psychol. Gen.* 124(3): 311–333.

Lachman ROY and Laughery KR (1968) Is a test trial a training trial in free recall learning? *J. Exp. Psychol.* 76(1, Pt.1): 40–50.

Landauer TK and Bjork RA (1978) Optimum rehearsal patterns and name learning. In: Gruneberg MM, Morris PE, and Sykes RN (eds.) *Practical Aspects of Memory*, pp. 625–632. London: Academic Press.

Lockhart RS and Craik FI (1990) Levels of processing: A retrospective commentary on a framework for memory research. *Can. J. Psychol.* 44(1): 87–112.

Logan JM and Balota DA (in press) Expanded versus equal interval spaced retrieval practice: Exploration of schedule of spacing and retention interval in younger and older adults. *Aging Neuropsychol. Cognit.*

Lowe G (1982) Alcohol-induced state-dependent learning: Differentiating stimulus and storage hypotheses. *Curr. Psychol. Res.* 2(3): 215–222.

Madigan S (1983) Picture memory. In: Yuille JC (ed.) *Imagery, Memory, and Cognition: Essays in Honor of Allan Paivio*, pp. 65–89. Hillsdale, NJ: Erlbaum Associates.

McDaniel MA (2007) Transfer. In: Roediger HL III, Dudai Y, and Fitzpatrick SM (eds.) *The Science of Learning and Memory: Concepts*, pp. 267–270. Oxford: Oxford University Press.

McDaniel MA, Anderson DC, Einstein GO, and O'Halloran CM (1989) Modulation of environmental reinstatement effects through encoding strategies. *Am. J. Psychol.* 102(4): 523–548.

McDaniel MA, Anderson JL, and Derbish MH (2007) Testing the testing effect in the classroom. *Eur. J. Cogn. Psychol.* 19: 494–513.

McDaniel MA, Kowitz MD, and Dunay PK (1989) Altering memory through recall: The effects of cue-guided retrieval processing. *Mem. Cognit.* 17(4): 423–434.

McDaniel MA and Masson ME (1985) Altering memory representations through retrieval. *J. Exp. Psychol. Learn. Mem. Cogn.* 11(2): 371–385.

Morris CD, Bransford JD, and Franks JJ (1977) Levels of processing versus transfer appropriate processing. *J. Verbal Learn. Verbal Behav.* 16(5): 519–533.

Paivio A (1969) Mental imagery in associative learning and memory. *Psychol. Rev.* 76(3): 241–263.

Paivio A, Rogers TB, and Smythe PC (1968) Why are pictures easier to recall than words? *Psychon. Sci.* 11(4): 137–138.

Payne DG (1986) Hypermnesia for pictures and words: Testing the recall level hypothesis. *J. Exp. Psychol. Learn. Mem. Cogn.* 12(1): 16–29.

Payne DG (1987) Hypermnesia and reminiscence in recall: A historic and empirical review. *Psychol. Bull.* 101: 5–27.

Rajaram S (1993) Remembering and knowing: Two means of access to the personal past. *Mem. Cognit.* 21(1): 89–102.

Rajaram S (1999) Assessing the nature of retrieval experience: Advances and challenges. In: Challis BH and Velichkovsky BM (eds.) *Stratification in Cognition and Consciousness*, pp. 255–275. Amsterdam, Netherlands: John Benjamins Publishing Company.

Rajaram S and Pereira-Pasarin L (2007) Collaboration can improve individual recognition memory: Evidence from immediate and delayed tests. *Psychon. Bull. Rev.* 14: 95–100.

Rajaram S and Roediger HL (1993) Direct comparison of four implicit memory tests. *J. Exp. Psychol. Learn. Mem. Cogn.* 19(4): 765–776.

Rajaram S and Roediger HL III (1997) Remembering and knowing as states of consciousness during retrieval. In: Cohen JD and Schooler JW (eds.) *Scientific Approaches to Consciousness*, pp. 213–240. Hillsdale, NJ: Lawrence Erlbaum Associates.

Reysen MB (2005) The effects of conformity on recognition judgments. *Memory* 13: 87–94.

Roediger HL (1990) Implicit memory: Retention without remembering. *Am. Psychol.* 45(9): 1043–1056.

Roediger HL III (2000) Why retrieval is the key process in understanding human memory. In: Tulving E (ed.) *Memory, Consciousness, and the Brain: The Tallinn Conference*, pp. 52–75. New York: Psychology Press.

Roediger HL and Blaxton TA (1987) Effects of varying modality, surface features, and retention interval on priming in word-fragment completion. *Mem. Cognit.* 15: 379–388.

Roediger HL III and Challis BH (1989) Hypermnesia: Improvements in recall with repeated testing. In: Izawa C (ed.) *Current Issues in Cognitive Processes: The Tulane Flowerree Symposium on Cognition*, pp. 175–199. Hillsdale, NJ: Lawrence Erlbaum Associates.

Roediger HL III and Guynn MJ (1996) Retrieval processes. In: Bjork EL and Bjork RA (eds.) *Memory*, pp. 197–236. San Diego, CA: Academic Press.

Roediger HL III and Karpicke JD (2006a) Test-enhanced learning: Taking memory tests improves long-term retention. *Psychol. Sci.* 17(3): 249–255.

Roediger HL and Karpicke JD (2006b) The power of testing memory: Basic research and implications for educational practice. *Perspect. Psychol. Sci.* 1: 181–210.

Roediger HL and McDermott K (1993) Implicit memory in normal human subjects. In: Boller F and Grafman J (eds.) *Handbook*

*of Neuropsychology,* vol. 8, pp. 63–131. Amsterdam: Elsevier.
Roediger HL and McDermott KB (1995) Creating false memories: Remembering words not presented in lists. *J. Exp. Psychol. Learn. Mem. Cogn.* 21(4): 803–814.
Roediger HL III, Meade ML, and Bergman ET (2001) Social contagion of memory. *Psychon. Bull. Rev.* 8(2): 365–371.
Roediger HL and Neely JH (1982) Retrieval blocks in episodic and semantic memory. *Can. J. Psychol.* 36(2): 213–242.
Roediger HL and Payne DG (1982) Hypermnesia: The role of repeated testing. *J. Exp. Psychol. Learn. Mem. Cogn.* 8(1): 66–72.
Roediger HL, Rajaram S, and Geraci L (2007) Three forms of consciousness in retrieving memories. In: Moscovitch M, Zelazo P, and Thompson E (eds.) *Cambridge Handbook of Consciousness*, pp. 251–288. London: Cambridge University Press.
Roediger HL, Rajaram S, and Srinivas K (1990) Specifying criteria for postulating memory systems. *Ann. N. Y. Acad. Sci.* 608: 572–595.
Roediger HL and Thorpe LA (1978) The role of recall time in producing hypermnesia. *Mem. Cognit.* 6(3): 296–305.
Roediger HL III, Weldon MS, and Challis BH (1989) Explaining dissociations between implicit and explicit measures of retention: A processing account. In: Roediger HL III and Craik FIM (eds.) *Varieties of Memory and Consciousness: Essays in Honour of Endel Tulving*, pp. 3–41. Hillsdale, NJ: Lawrence Erlbaum Associates.
Roediger HL, Weldon MS, Stadler ML, and Riegler GL (1992) Direct comparison of two implicit memory tests: Word fragment and word stem completion. *J. Exp. Psychol. Learn. Mem. Cogn.* 18(6): 1251–1269.
Roenker DL, Thompson CP, and Brown SC (1971) Comparison of measures for the estimation of clustering in free recall. *Psychol. Bull.* 76(1): 45–48.
Rosner SR (1970) The effects of presentation and recall trials on organization in multitrial free recall. *J. Verbal Learn. Verbal Behav.* 9(1): 69–74.
Rundus D (1971) Analysis of rehearsal processes in free recall. *J. Exp. Psychol.* 89: 63–77.
Schacter DL (1982) *Stranger behind the Engram: Theories of Memory and the Psychology of Science*. Hillsdale, NJ: Erlbaum Associates.
Schacter DL (1987) Implicit memory: History and current status. *J. Exp. Psychol. Learn. Mem. Cogn.* 13(3): 501–518.
Schacter DL (1990) Introduction to 'Implicit memory: Multiple perspectives.' Bull. Psychon. Soc.28(4): 338–340.
Schacter DL (2001) *Forgotten Ideas, Neglected Pioneers: Richard Semon and the Story of Memory*. New York: Psychology Press.
Schacter DL, Bowers J, and Booker J (1989) Intention, awareness, and implicit memory: The retrieval intentionality criterion. In: Lewandowsky S, Dunn JC, and Kirsner K (eds.) *Implicit Memory: Theoretical Issues*, pp. 47–65. Hillsdale, NJ: Lawrence Erlbaum Associates.
Schacter DL, Eich JE, and Tulving E (1978) Richard Semon's theory of memory. *J. Verbal Learn. Verbal Behav.* 17(6): 721–743.
Schwartz BL, Travis DM, Castro AM, and Smith SM (2000) The phenomenology of real and illusory tip-of-the-tongue states. *Mem. Cognit.* 28(1): 18–27.
Semon R (1921) *The Mneme*. London: Allen and Unwin.
Shapiro SR and Erdelyi MH (1974) Hypermnesia for pictures but not for words. *J. Exp. Psychol.* 103: 1218–1219.
Slamecka NJ (1968) An examination of trace storage in free recall. *J. Exp. Psychol.* 76(4, Pt.1): 504–513.
Smith SM (1988) Environmental context – dependent memory. In: Davies GM and Thomson DM (eds.) *Memory in Context: Context in Memory*, pp. 13–34. Oxford: John Wiley and Sons.
Smith SM, Glenberg A, and Bjork RA (1978) Environmental context and human memory. *Mem. Cognit.* 6(4): 342–353.
Spitzer (1939) Studies in retention. *J. Educ. Psychol.* 30: 641–656.
Srinivas K and Roediger HL (1990) Classifying implicit memory tests: Category association and anagram solution. *J. Mem. Lang.* 29: 389–412.
Thompson CP, Wenger SK, and Bartling CA (1978) How recall facilitates subsequent recall: A reappraisal. *J. Exp. Psychol. Hum. Learn. Mem.* 4(3): 210–221.
Thomson DM and Tulving E (1970) Associative encoding and retrieval: Weak and strong cues. *J. Exp. Psychol.* 86(2): 255–262.
Tulving E (1962) Subjective organization in free recall of 'unrelated' words. *Psychol. Rev.* 69(4): 344–354.
Tulving E (1967) The effects of presentation and recall of material in free-recall learning. *J. Verbal Learn. Verbal Behav.* 6(2): 175–184.
Tulving E (1974) Cue-dependent forgetting. *Am. Sci.* 62(1): 74–82.
Tulving E (1983) *Elements of Episodic Memory*. New York: Oxford University Press.
Tulving E (1985) Memory and consciousness. *Can. Psychol.* 26(1): 1–12.
Tulving E (2002) Episodic memory: From mind to brain. *Annu. Rev. Psychol.* 53(1): 1–25.
Tulving E and Osler S (1968) Effectiveness of retrieval cues in memory for words. *J. Exp. Psychol.* 77(4): 593–601.
Tulving E and Pearlstone Z (1966) Availability versus accessibility of information in memory for words. *J. Verbal Learn. Verbal Behav.* 5(4): 381–391.
Tulving E and Thomson DM (1973) Encoding specificity and retrieval processes in episodic memory. *Psychol. Rev.* 80(5): 352–373.
Warrington EK and Weiskrantz L (1968) A study of learning and retention in amnesic patients. *Neuropsychologia* 6(3): 283–291.
Warrington EK and Weiskrantz L (1970) Amnesic syndrome: Consolidation or retrieval? *Nature* 228: 628–630.
Weingartner H, Miller H, and Murphy DL (1977) Mood-state-dependent retrieval of verbal associations. *J. Abnorm. Psychol.* 86(3): 276–284.
Weldon MS (1991) Mechanisms underlying priming on perceptual tests. *J. Exp. Psychol. Learn. Mem. Cogn.* 17: 526–541.
Weldon MS (2001) Remembering as a social process. In: Medin DL (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 40, pp. 67–120. San Diego, CA: Academic Press.
Weldon MS and Bellinger KD (1997) Collective memory: Collaborative and individual processes in remembering. *J. Exp. Psychol. Learn. Mem. Cogn.* 23(5): 1160–1175.
Weldon MS, Blair C, and Huebsch D (2000) Group remembering: Does social loafing underlie collaborative inhibition? *J. Exp. Psychol. Learn. Mem. Cogn.* 26(6): 1568–1577.
Weldon MS and Roediger HL (1987) Altering retrieval demands reverses the picture superiority effect. *Mem. Cognit.* 15: 269–280.
Wheeler MA, Ewers M, and Buonanno JF (2003) Different rates of forgetting following study versus test trials. *Memory* 11(6): 571–580.
Wheeler MA and Roediger HL (1992) Disparate effects of repeated testing: Reconciling Ballard's (1913) and Bartlett's (1932) results. *Psychol. Sci.* 3(4): 240–245.
Wright DB and Klumpp A (2004) Collaborative inhibition is due to the product, not the process, of recalling in groups. *Psychon. Bull. Rev.* 11(6): 1080–1083.

# 2.17 Remembering and Knowing

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> This ultimate puzzle, the subjective experience of consciousness, is perhaps a good place for any purely scientific survey, namely one of objective facts, to cease.
>
> (Greenfield, 1997: 192)

> . . . the peculiarity of individual experience does not place the subject of individual experience outside the realm of scientific inquiry. Any explanation of consciousness must account for subjective states of awareness. . .
>
> (Searle, 1997: 49–50)

## 2.17.1 Introduction

The mystery of consciousness seems to have resisted scientific investigation for at least two main reasons, first, because consciousness is apparently unitary and, second, because it is subjective. It is difficult for science to deal with phenomena that cannot be broken down into constituent parts that can be investigated separately, as well as in conjunction. Thus, little theoretical progress was made in memory research for so long as memory was thought of as being a single mental faculty – memory is memory – and significant progress has been made only since memory began to be classified into various systems and component processes. Similarly, little progress can be made in understanding consciousness for so long as consciousness is thought of just as consciousness. Consciousness has to be broken down and classified into different natural kinds as a precondition for scientific inquiry. This chapter concerns one such classification, a simple classification of consciousness in relation to memory that was proposed by Endel Tulving, along with a paradigm for investigating the different kinds of consciousness (Tulving, 1983, 1985).

Tulving's (1983, 1985) original proposal was of three kinds of consciousness, each reflecting one of three memory systems. The three kinds of consciousness were autonoetic, noetic, and anoetic, which respectively mean self-knowing, knowing, and not knowing. The three corresponding memory systems were episodic, semantic, and procedural memory. Only autonoetic and noetic consciousness involve awareness of memory. Anoetic consciousness is bound to the present, not the past, and involves awareness of the current situation. Autonoetic consciousness allows awareness of oneself in a previous situation, in the sense of what has been called mental time travel. It allows one to reexperience previous events and to relive them mentally, including one's own part in them. It is characteristic of episodic memory, which therefore entails something more than, or other than, autobiographical memory.

Autobiographical memory includes facts known about one's past in an abstract, historical sense, without any-ability to reexperience those autobiographical events or relive them mentally. It is noetic consciousness that gives rise to awareness of this kind, and it is characteristic of semantic memory, which also includes all the general knowledge that one has acquired about the world.

The remember-know paradigm was introduced by Endel Tulving (1985) as a procedure for obtaining what have been called subjective (or first-person) reports of autonoetic and noetic awareness. In this paradigm, for each item retrieved participants are instructed to report "whether they actually 'remember' its occurrence in the list or whether they simply 'know' on some other basis that the item was a member of the study list" (Tulving, 1985: 8). The proportion of remembered items gives a direct measure of autonoetic awareness, whereas the proportion of known items reflects noetic awareness. It follows that remembering, as a state of awareness, gives a better measure of retrieval from episodic memory than other more traditional measures such as recall or recognition.

Since the introduction of this paradigm, it has been significantly modified and very widely used, such that there is now a substantial body of research in which participants have been required to make remember and know responses at the time of retrieval. A large number of empirical facts about autonoetic and noetic awareness have been established. Other theoretical accounts than that provided by the distinction between episodic and semantic systems have also been invoked to account for these facts. These include dual-process models of recognition that distinguish between two independent processes, recollection and familiarity, which are assumed to respectively give rise to corresponding recollective experiences (that is to remembering) and to feelings of familiarity (Mandler, 1980; Jacoby, 1991). Another processing account distinguishes between the distinctiveness and the fluency of the processing involved, with distinctiveness giving rise to remembering and fluency giving rise to knowing (Rajaram, 1996). A third approach has been to try to model remember and know responses using signal detection measures of trace strength and response criteria in recognition tests. According to some of these models, remembering simply represents the adoption of more stringent response criteria than that adopted in deciding whether the item was a member of the study list (Donaldson, 1996; Hirshman, 1998; Inoue and Bellezza, 1998).

Studies using the remember-know paradigm, particularly the early ones, were widely criticized because of the so-called subjectivity of remember and know responses, which to some critics puts the paradigm outside the realm of scientific inquiry. However, such criticism has become more muted of late, mainly by virtue of the empirical facts that have been discovered and the theoretical understanding of them that has been achieved. There are also purely rational arguments against the overly narrow view of scientific method and explanation that this criticism embodies.

The aim of this chapter is to survey what has been achieved by studies that have made use of the remember-know paradigm. To that end, the paradigm itself is described in more detail in the next section of the chapter. This is followed by a section that argues, on rational grounds, for the objectivity of the subjective experiences of consciousness measured by remember and know responses. The next section of the chapter surveys many of the empirical facts that have been gleaned experimentally, especially from earlier studies. After that, the major theoretical accounts are briefly outlined. Next follows a lengthy section concerned with more recent empirical findings and current theoretical issues. The chapter concludes with a critical theoretical evaluation.

## 2.17.2 The Paradigm

Although in introducing the paradigm Endel Tulving (1985) used free recall, cued recall, and recognition tests, nearly all the subsequent studies that made use of it used recognition tests. The two most significant modifications to the paradigm in part reflect this rather restricted usage. The first modification was to identify know responses in the instructions given to participants closely with familiarity rather with some other basis. This modification has occurred gradually, over a period of years, in different studies. Instructions often emphasize the importance of having strong feelings of familiarity or knowing, or being highly confident of such feelings. The second modification was to add a guess response (Mantyla, 1993; Gardiner et al., 1996). Both these modifications have some theoretical importance. Identifying know responses with familiarity links those responses more directly to semantic memory and to the familiarity process in dual-process models. The addition of a guess response has implications both for a familiarity process and for signal detection models. But the primary reason for allowing this response was methodological. It allows for recognition decisions that are more strategically based and not associated either with experiences of remembering or with knowing. Guess responses therefore remove a potential confounding of such strategically based recognition decisions with remember or know responses. They also provide a default response if participants realize that their initial recognition decision was mistaken. There are thus good methodological reasons for recommending that the paradigm should usually include guess responses (Gardiner and Conway, 1999). This paradigm is summarized schematically in **Table 1**. For a full version of typical written test instructions that includes those for guess responses, see Gardiner and Richardson-Klavehn (2000).

It is also good practice to check the validity of remember, know, and guess responses by having participants provide descriptions of the reasons underlying a random selection of them after the test is over. It is important that participants provide evidence of contextually relevant mental details for remember responses and do not provide such evidence for know or guess responses. And such descriptions can be of considerable interest in their own right (Gardiner et al., 1998a). Neither the use of guess responses nor that of posttest checks of the validity of all three kinds of responses has become universal practice, however, even in more recent studies, despite the increased risk of obtaining potentially misleading results (see, e.g., Gardiner et al., 1996, 1997).

**Table 1** The usual remember-know (guess) paradigm in recognition memory tests

| |
|---|
| ***Procedure*** |
| Study tasks |
| Retention interval |
| Recognition tests (Old/New) |
| If Old, then Remember, Know, or Guess |
| ***Response definitions*** |
| Old/New: Test item occurred/did not occur in the study list |
| Remember: Test item brought back to mind some specific recollection of something you thought about when it occurred in the study list |
| Know: Test item does not bring back to mind something you thought about when it occurred in the study list, but it seemed strongly familiar in the experimental context |
| Guess: Test item did not give rise either to experiences of remembering or of knowing it occurred in the study list, but you have other reasons for guessing that it might have done |

## 2.17.3 The Objectivity of Subjective Experiences of Consciousness

Criticism that the subjectivity of the states of awareness reported by remember and know responses means that those responses do not yield scientific data is misguided. In effect, this criticism argues that a recognition response is objective but a remember or know response is subjective. But remember and know responses (guess responses, too) are simply a partitioning of the recognition response into some constituent components, and so, by the same token, the recognition response is simply based on the sum of those components. A recognition response also reflects subjective states of awareness. It is difficult, looking at the four response definitions given in **Table 1**, to make a convincing case for there being between the first definition and the three definitions that follow it a categorical shift from objectivity to subjectivity.

Remember and know responses, respectively, reflect distinct populations of experiences of autonoetic and noetic awareness, and it is critical for a scientific approach that these natural kinds of subjective experiences are treated at the population level, not at the level of individual instances of such experiences, which are inevitably idiosyncratic (Gardiner, 2001). Psychology is a biological science, not a physical one, and biology is characterized by population thinking, not by essentialism (Mayr, 1982). Every individual instance of remembering may be unique, just as every individual member of a biological species is unique. In each case, that which is uniquely individual may be impenetrable to science, but the population to which individual instances conform is not impenetrable to science, whether of a biological species or of a mental state of awareness. Therein lies the importance of a conceptual classification of so-called subjective consciousness.

But, as the saying goes, the proof of the pudding is in the eating. For data to be amenable to science, those data must yield phenomena that are systematic, replicable, and intelligible theoretically. It was by no means a foregone conclusion that this would turn out to be the case using the remember-know paradigm, and early studies using the paradigm were primarily concerned with seeing whether such a case could be established empirically. That is, they were concerned initially with whether or not, and then under what circumstances and for what reasons, functional dissociations might be observed between the reported states of awareness. Functional dissociation refers here to the discovery of dissociative effects of experimental manipulations on the reported states of awareness or of dissociative effects between them in comparing different subject populations. The first such study was by Gardiner (1988), who found that the beneficial effects both of deeper levels of processing and the detrimental effects of longer retention intervals were essentially confined to remembering. This kind of outcome was soon replicated by other studies that included the effects of word frequency (Gardiner and Java, 1990), undivided versus divided attention, use of a digit-monitoring task (Gardiner and Parkin, 1990), and the picture superiority effect (Rajaram, 1993). The first study reporting dissociative effects among different subject populations was by Parkin and Walter (1992), who found that reports of remembering were greatly reduced in older compared with younger adults. This kind of outcome that was soon replicated by other studies that included patients with Alzheimer's disease (Dalla Barba, 1997), patients with schizophrenia (Huron et al., 1995), and amnesic patients (Knowlton and Squire, 1995).

## 2.17.4 Functional Dissociation

It is important to appreciate that functional dissociation between remembering and knowing cannot reliably be inferred from more familiar measures of recognition memory such as old versus new. To illustrate this, each of the following subsections of the chapter begins with a figure that simply shows overall proportions of correct responses from four different studies, and then goes on to show how those proportions were partitioned between remembering and knowing. This initial survey ignores false alarm rates, not because they are unimportant but because they do not much affect the conclusions to be discussed.

### 2.17.4.1 Experimental Manipulations

**Figure 1** shows the proportions of study list items that were correctly identified as old from each of four studies involving different experimental manipulations. The first example is taken from a levels-of-processing study (Gardiner et al., 1996) in which participants had to either report a semantic associate for a presented word or to report any two letters not present in the word, and it shows a large levels-of-processing effect. In the second example, study list words were presented rapidly with the instruction to monitor the number of words that contained letters that were blurred (there were none), a task intended to encourage perceptual processing and discourage conceptual processing (Gregg and Gardiner, 1994). At test, half the words were presented in the same visual mode, and half were presented auditorily. Recognition was much more likely when study and test modes were the same. In the third example, participants studied a mixed list of words and pronounceable nonwords (Gardiner and Java, 1990), but this material manipulation had little effect on recognition. And in the final example, participants heard a set of musical phrases taken from folk songs in a culture with which they were unfamiliar (Polish, for English participants, and vice versa) either just once or on three successive study trials before the test (Gardiner and Radomski, 1999). Not surprisingly, the musical phrases were much more likely to be recognized following three study trials than following only one.

**Table 2** summarizes the full partitioning of these recognition data between remember and know responses, and it illustrates four different kinds of outcome. The levels-of-processing effect occurred in remember but not know responses. The effects of study/test mode occurred in know but not remember responses. For words and nonwords, there was a crossover effect such that word recognition was accompanied by more remember than know responses, whereas nonword recognition was accompanied by more know than remember responses. But the effect of study trials on the recognition of musical phrases was similar for both responses, with increased remembering and increased knowing.

What is important about the pattern of results illustrated in **Table 2** is that it demonstrates what has been termed functional independence between remembering and knowing (Gardiner and Conway, 1999). That is, there are variables that affect remembering but not knowing; variables that affect knowing but not remembering; variables that have opposite effects on remembering and knowing; and variables that have similar effects on remembering and knowing. Experimental conditions can affect the two states of awareness, separately or jointly, in ways that cannot be inferred from the overall proportions of items that are correctly recognized.

These kinds of outcomes have been replicated many times in various different studies. Among many other examples, selective advantages to remembering have been found for intentional versus incidental learning (Macken and Hampson, 1993), for slow versus fast presentation rates (Dewhurst and

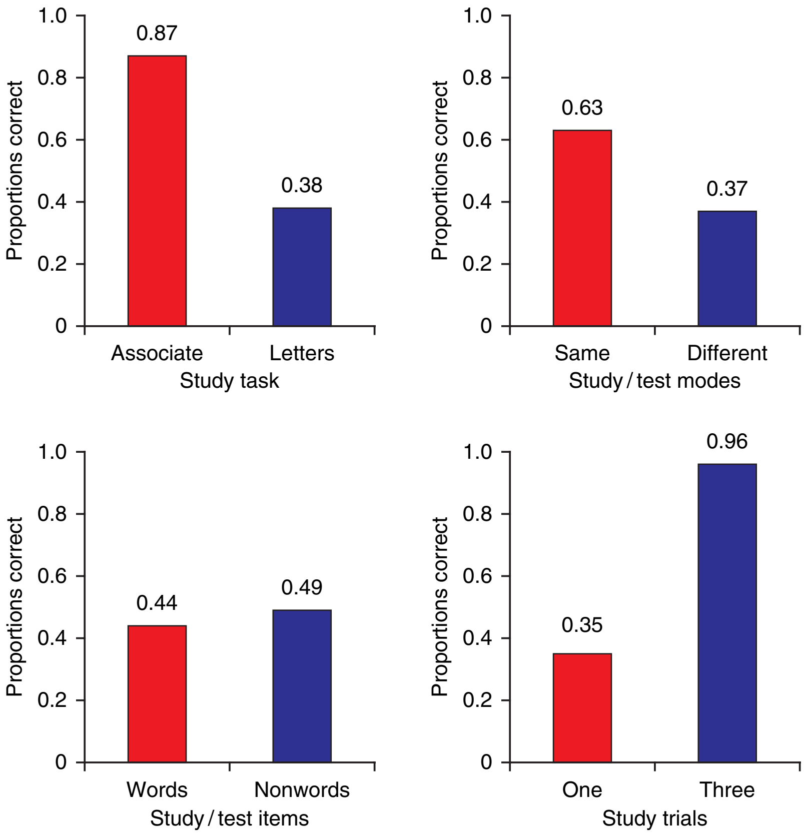


**Figure 1** Effects of some experimental manipulations on overall recognition (correct 'old' response proportions). These examples, going clockwise from the top left-hand corner, are taken, respectively, from experiments by Gardiner JM, Java RI, and Richardson-Klavehn A (1996) How levels of processing really influences awareness in recognition memory. *Can. J. Psychol.* 50: 114–122; Gregg VH and Gardiner JM (1994) Recognition memory and awareness: A large effect of study-test modalities on "know" responses following a highly perceptual orienting task. *Eur. J. Cognit. Psychol.* 6: 137–147; Gardiner JM and Java RI (1990) Recollective experience in word and nonword recognition. *Mem. Cognit.* 18: 23–30; and Gardiner JM and Radomski E (1999) Awareness of recognition memory for Polish and English folk songs in Polish and English folk. *Memory* 7: 461–470; all figures used with permission.

Anderson, 1999), and for orthographically distinctive versus orthographically common words (Rajaram, 1998). Serial position effects occur in remembering and not in knowing, and prior recall tests boost remembering but do not boost knowing (Jones and Roediger, 1995).

Selective increases in knowing but not in remembering have been found to result from presenting identical (Rajaram, 1993) or associatively related (Rajaram and Geraci, 2000) test primes and from cohort activation in a preceding lexical decision task (Dewhurst and Hitch, 1997). Dividing attention by suppressing the processing of foveal information also selectively facilitates knowing (Mantyla and Raudsepp, 1996). Opposite effects on remembering and knowing have been found for massed versus spaced repetitions of study list items (Parkin and Russo, 1993); for the revelation effect, which occurs when gradually revealing words at test compared with presenting them normally (LeCompte, 1995); and from encoding faces with respect to their similarity versus encoding them with respect to their distinctiveness (Mantyla, 1997). Parallel increases in both remembering and in knowing have also been found when manipulating response deadlines in recognition tests to compare speeded with unspeeded recognition decisions (Gardiner et al., 1999).

### 2.17.4.2 Special Populations

Figure 2 shows the proportions of study list items that were correctly identified as old from each of four studies involving different special populations. The first example is taken from a study involving amnesic

**Table 2** Effects of some experimental manipulations on remembering and knowing (for correct 'old' response proportions)

| *Manipulation* | *Condition* | *Remember* | *Know* |
|---|---|---|---|
| Study tasks | Associate | .72 | .15 |
| | Letters | .18 | .20 |
| Study/test modes | Visual/visual | .11 | .52 |
| | Visual/ auditory | .10 | .27 |
| Study/test items | Words | .28 | .16 |
| | Nonwords | .19 | .30 |
| Study trials | One | .14 | .21 |
| | Three | .37 | .32 |

These examples are taken, respectively, from experiments by Gardiner JM, Java RI, and Richardson-Klavehn A (1996) How levels of processing really influence awareness in recognition memory. *Can. J. Psychol.* 50: 114–122; Gregg VH and Gardiner JM (1994) Recognition memory and awareness: A large effect of study-test modalities on ''know'' responses following a highly perceptual orienting task. *Eur. J. Cognit. Psychol.* 6: 137–147; Gardiner JM and Java RI (1990) Recollective experience in word and nonword recognition. *Mem. Cognit.* 18: 23–30; and Gardiner JM and Radomski E (1999) Awareness of recognition memory for Polish and English folk songs in Polish and English folk. *Memory* 7: 461–470.

patients (Schacter et al., 1997a). In the second example, the study compared the performance of younger with older adults (Perfect et al., 1995). The third example is taken from the study by Huron et al. (1995) involving schizophrenic patients. And the final study involved high-functioning adults with autistic spectrum disorders or Asperger's syndrome (Bowler et al., 2000). In the first three of these special populations, recognition performance was impaired to varying degrees, but there was little difference between the performance of adults with autistic spectrum disorders and that of an appropriately matched control group.

**Table 3** summarizes the full partitioning of these recognition data between remember and know responses. The pattern of results here is rather different from that in **Table 2**, but it is clear that the two states of awareness differ in different populations in ways that cannot be inferred from the overall proportions of items that are correctly recognized. Remembering but not knowing was greatly reduced in the amnesic patients. Remembering was also greatly reduced in older compared with younger adults, but this reduction was largely offset by increased knowing. Schizophrenic patients also remembered less than an appropriately matched control group, but there was little difference in the amount of knowing. And, though overall recognition was much the same for adults with autistic spectrum disorders as for the control group, this masked a trade-off between reduced remembering and increased knowing.

Although these kinds of outcomes have also been replicated in other studies, there is considerable variability among some of these studies. Other studies involving amnesic patients have found reduced knowing as well as reduced remembering (Knowlton and Squire, 1995). Other studies involving older adults found increased knowing, as well as reduced remembering (Parkin and Walter, 1992), particularly when encoding was not controlled by specific study tasks (cf. Perfect et al., 1995). Further studies have confirmed the selective deficit in remembering in schizophrenic patients (Danion et al., 1999) and in adults with autistic spectrum disorders, though in the latter case this deficit is not always accompanied by increased knowing (Bowler et al., 2007).

Other special populations in which remembering and knowing have been investigated include epileptic patients with temporal lobe lesions. Blaxton and Theodore (1997) found that patients with left temporal lobe lesions reported far more knowing than remembering, whereas patients with right temporal lobe lesions reported far more remembering than knowing. There is also some evidence of reduced remembering in recognition memory for threat-related words in clinical anxiety states (Mogg et al., 1992). Alcohol (Curran and Hildebrandt, 1999) and other drugs such as lorazepam (Curran et al., 1993) and midazolam (Hirshman et al., 2002) can also adversely and selectively affect remembering, but emotionally negative stimuli tend to be better remembered than positive or neutral stimuli (Ochsner, 2000).

## 2.17.5 Major Theories

Such findings have attracted considerable theoretical interest, and at least four major theories were initially advanced to account for them.

### 2.17.5.1 Episodic and Semantic Memory Systems

According to Tulving (1983, 1985), remembering is an expression of autonoetic consciousness and hence retrieval from episodic memory, and knowing is an expression of noetic consciousness and hence retrieval from semantic memory. Thus, retrieval from both systems contributes to performance in recognition

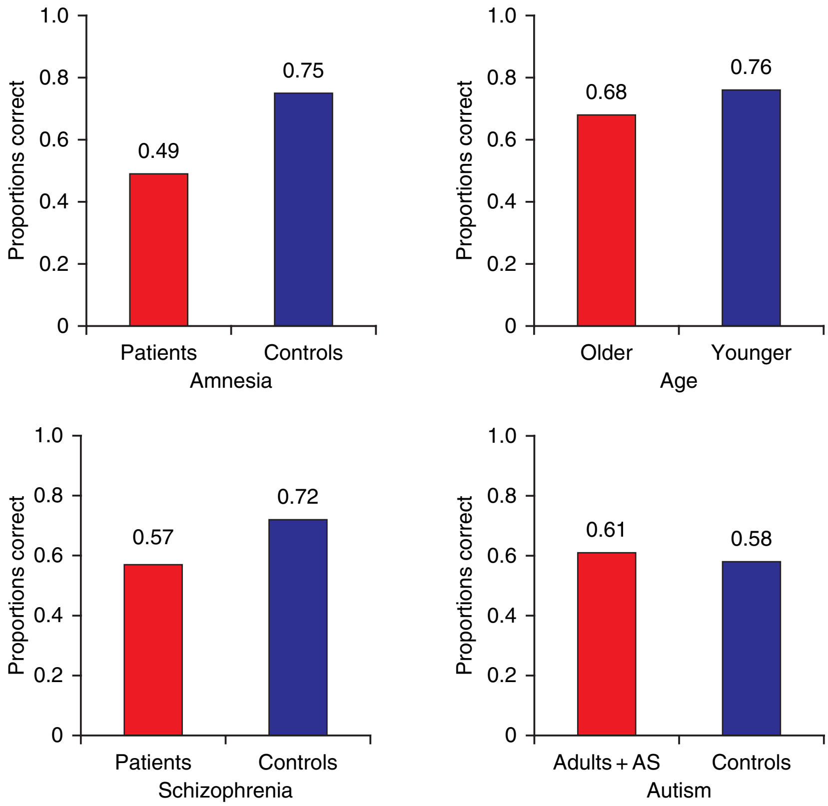


**Figure 2** Differences between recognition (correct 'old' response proportions) in some special populations. AS stands for Asperger's syndrome, a mild form of autism. These examples, going clockwise from the top left-hand corner, are taken, respectively, from experiments by Schacter DL, Koutstaal W, Johnson MK, Gross MS, and Angell KE (1997a) False recollection induced by photographs: A comparison of older and younger adults. *Psychol. Aging* 12: 203–215; Perfect TJ, Williams RB, and Anderton-Brown C (1995) Age differences in reported recollective experience are due to encoding effects, not response bias. *Memory* 3: 169–186; Huron C, Danion JM, Giacomoni F, Grange D, Robert P, and Rizzo L (1995) Impairment of recognition memory with, but not without, conscious recollection in schizophrenia. *Am. J. Psychiatry* 152: 1737–1742; and Bowler DM, Gardiner JM, and Grice S (2000) Episodic memory and remembering in adults with Asperger's syndrome. *J. Autism Dev. Disord.* 30: 305–316; all figures used with permission.

tests, among others. Tulving (1995) additionally proposed an SPI model of relations between these systems such that that encoding into semantic and episodic systems is serial (S), storage is parallel (P), and retrieval is independent (I). Given some minimal registration of the occurrence of an event, that event may only be stored in the semantic system. Given more attention at encoding and more conscious control, the event may be further encoded into episodic memory. Events may be stored in both systems but retrieved independently from them. Tulving (1993) also proposed a coordination hypothesis, which concerns the relation between awareness at encoding and awareness at retrieval. According to this hypothesis, the retrieval of information from a system is possible only at a level of awareness that does not exceed the level of awareness achieved at encoding. In other words, it is not possible for the retrieval of information that has only been encoded into the semantic system to give rise to autonoetic awareness, however much time and conscious effort goes into the retrieval attempt.

Much of the evidence is consistent with this account, but more critical to it is recent evidence concerning the underlying neuroanatomical substrates of episodic and semantic systems. For example, in an event-related potentials (ERP) study, Mangels et al. (2001) showed that whereas some minimal level of encoding (with divided attention) is sufficient to lead to knowing in recognition memory, remembering depends on more

**Table 3** Differences between remembering and knowing in some special populations (for correct "old" response proportions)

| *Condition* | *Group* | *Remember* | *Know* |
|---|---|---|---|
| Amnesia | Patients | .21 | .28 |
| | Controls | .50 | .25 |
| Age | Older adults | .17 | .51 |
| | Younger adults | .53 | .23 |
| Schizophrenia | Patients | .23 | .34 |
| | Controls | .39 | .33 |
| Autism | Adults with Asperger's | .36 | .25 |
| | Controls | .47 | .11 |

These examples are taken, respectively, from experiments by Schacter DL, Koutstaal W, Johnson MK, Gross MS, and Angell KE (1997a) False recollection induced by photographs: A comparison of older and younger adults. *Psychol. Aging* 12: 203–215; Perfect TJ, Williams RB, and Anderton-Brown C (1995) Age differences in reported recollective experience are due to encoding effects, not response bias. *Memory* 3: 169–186; Huron C, Danion JM, Giacomoni F, Grange D, Robert P, and Rizzo L (1995) Impairment of recognition memory with, but not without, conscious recollection in schizophrenia. *Am. J. Psychiatry* 152: 1737–1742; and Bowler DM, Gardiner JM, and Grice S (2000) Episodic memory and remembering in adults with Asperger's syndrome. *J. Autism Dev. Disord.* 30: 305–316.

extensive brain activity, including sustained interaction of frontal and posterior regions. Other studies (to be discussed later) have provided evidence that implicates hippocampal as well as frontal regions of the brain in remembering (Eldridge et al., 2000; Wheeler and Stuss, 2003), and there is increasing evidence of functional dissociations between remembering and knowing at the level of the brain (Wheeler and Buckner, 2004). As Tulving (2002) put it in the title of a recent review, episodic memory now extends "from mind to brain."

### 2.17.5.2 Memory Process Accounts

Among the most prominent alternative theories are those that distinguish between two kinds of processes, rather than two memory systems.

#### *2.17.5.2.1 Recollection and familiarity*

Dual-process models of recognition memory distinguish between recollection and familiarity processes, each of which is assumed to give rise to corresponding experiences of recollection and familiarity (Mandler, 1980; Jacoby, 1991). These two processes are assumed to be independent and to vary in the extent to which they are consciously controlled. Recollection is generally thought to be a relatively slow, effortful process that depends on conscious control, whereas familiarity is thought to be a relatively fast, automatic process that does not depend on conscious control. Because experiences of recollection and familiarity are indicated by remember and know responses, the remember-know paradigm is also a procedure that can be used to test the relative contributions these two processes make to recognition. The independence assumption means that some recognition responses are based jointly on recollection and familiarity, and so an independent remember-know model is used to provide estimates of the two processes (Yonelinas and Jacoby, 1995). In this model, remember responses are taken to provide a relatively direct estimate of the recollection process, but the familiarity process is estimated by dividing the proportions of know responses by one minus the proportions of remember responses. For a version of the paradigm that allows independence between remember and know responses, see Higham and Vokey (2004).

The use of this procedure to provide such process estimates has proved to be quite controversial (Richardson-Klavehn et al., 1996; Jacoby et al., 1997). Nonetheless, in a comprehensive review Yonelinas (2002) showed that there is quite good agreement between the conclusions drawn from this procedure and from other procedures used to provide estimates of recollection and familiarity, namely, the process-dissociation procedure (Jacoby, 1991) and receiver operating characteristics (ROCs). Moreover, although the processes of recollection and familiarity offer an alternative theory to that offered by the distinction between episodic and semantic memory systems, there is in broad terms a great deal of convergence between these two accounts. Even know responses, which have generated more controversy, have a parallel meaning from each theoretical perspective. In dual-process models, they indicate familiarity in the absence of recollection. In the systems approach, they indicate semantic memory in the absence of episodic memory. But theorists who have adopted this process account are primarily concerned with the underlying processes rather than with remembering and knowing *per se*, whereas theorists who have taken the systems approach focus more on the actual states of awareness. So one important difference between the two approaches is whether the primary data are regarded as estimates inferred from remember and know responses or remembering and knowing as such.

#### 2.17.5.2.2 Distinctiveness and fluency

Results of earlier studies using the remember-know paradigm suggested that remember and know responses were influenced, respectively, by conceptual and perceptual variables and hence by conceptual and perceptual processes (Rajaram, 1993), thereby linking them with the transfer-appropriate processing framework (Roediger et al., 1989). However, results from more recent studies forced a revision of this view, as some perceptual variables were found to influence remembering but not knowing, and some conceptual variables were found to influence knowing but not remembering. Rajaram (1996), for example, found that a size congruency effect, that is, superior recognition memory for pictures presented in the same size at study and test rather than in alternative sizes, occurred only in remembering. And Mantyla (1997) found that grouping faces that seemed similar into several conceptual categories, a relational task that depends on the use of schema in semantic memory, increased knowing. He also found that rating the facial distinctiveness of different faces increased remembering.

Such findings led to the proposal of a distinctiveness/fluency framework according to which remembering benefits from the distinctiveness of the processing and knowing benefits from its fluency, regardless of whether that processing is conceptual or perceptual (Rajaram, 1996, 1999). It is important to note that in this approach, the distinctiveness or fluency of processing is not inferred from remember and know responses but independently based on other theoretical considerations. Though this approach offers a different theoretical perspective, nonetheless in some respects it complements memory systems and dual-process models. Distinctiveness implies greater attention and more elaborative processing, which will increase encoding into episodic memory or enhance a recollection process. Fluency implies less attention and minimal processing, which may increase encoding into semantic but not into episodic memory or enhance a familiarity process.

### 2.17.5.3 Signal Detection Models

The three foregoing theories all converge on the conclusion that remembering and knowing reflect two distinct underlying components of memory, though they differ in their characterization of those components. The possibility that remembering and knowing might simply reflect a single memory component has been raised by signal detection models. That remembering and knowing might simply map onto single-trace strength, with higher or lower degrees of confidence, had been discounted on the basis of some early studies in which sure versus unsure recognition responses were shown to yield different patterns of results to remember versus know responses (Gardiner and Java, 1990; Parkin and Walter, 1992; Rajaram, 1993). However, Donaldson (1996) showed that a single-trace signal detection model could provide an approximate fit to results from the remember-know paradigm, and this approach has recently been followed up by other theorists (Hirshman and Henzler, 1998; Dunn, 2004; Wixted and Stretch, 2004). The essential claim is that remembering and knowing reflect decision processes rather than memory and are simply a matter of confidence. A more stringent response criterion is set for remember responses, and a more lenient criterion, corresponding with the overall criterion for recognition, includes know responses.

This approach has been supported by meta-analyses of results from many different studies as well as by results from individual experiments, but it has also been strongly criticized on various grounds, and there are quite technical arguments involving the appropriateness of the various different assumptions and measures that can be used in signal detection models. The assumptions and measures used by Donaldson (1996) have subsequently been shown to support a dual-component interpretation, not his original model, by yielding higher estimates of trace strength when those estimates are derived from both know and remember responses rather than from remember responses alone (Gardiner and Gregg, 1997; Gardiner and Conway, 1999; Gardiner et al., 2002). If remembering and knowing merely reflect different response criteria such estimates should be the same. But the assumptions and measures that yield those outcomes have been discredited in favor of others that have been shown to support a one-dimensional signal detection model (Dunn, 2004; Macmillan et al., 2005).

## 2.17.6 Further Empirical Extensions and Theoretical Issues

In recognition memory, noetic awareness usually corresponds with familiarity in the sense of some recent but unremembered encounter with the test item. But with respect to general knowledge in semantic memory, noetic awareness does not refer to some recent but unremembered encounter but rather to "just knowing" that something is so. Conway et al. (1997) gave UK undergraduate students forced-choice tests of knowledge acquired in various courses immediately at the end of the courses and again some months later at the end of the academic year. In these tests, students reported whether they remembered their answer, just knew it, chose it because it seemed more familiar (in the sense of having been encountered recently), or had simply guessed. In the initial tests, top-scoring students reported more remembering than students with lower scores. In the final tests there was a 'remember-to-know' shift. Those same top-scoring students reported more just knowing the answers than students with lower scores. Lower-scoring students showed a similar remember-to-know shift, but it was less pronounced. There were no such trends in reported familiarity or guessing. These findings have been replicated in a similar study carried out in Australia (Herbert and Burt, 2001). They illustrate the role of remembering in the acquisition and schematization of knowledge. Initially, remembering the learning episodes is helpful, but over time, with further study and coursework, the ability to remember the original learning episodes is lost and knowledge acquired from them becomes schematized in semantic memory.

But remembering may not be necessary for the acquisition of knowledge. There are amnesic patients who seem to have acquired normal semantic memory knowledge despite showing little or no evidence of any experiences of remembering. One such case, initially reported by Vargha-Khadem et al. (1997), is that of Jon, a young adult with early-onset developmental amnesia caused by selective bilateral damage to the hippocampus. Jon has above-average intellectual abilities, and he has acquired good general knowledge, including good language skills. Nonetheless, though he understands the distinction between remembering and knowing and will follow instructions for remember and know responses in recognition tests, there is no evidence that he experiences remembering in such tests (Baddeley et al., 2001; Gardiner et al., 2006a). When asked to describe what it was that he remembered about those items he claimed to remember, Jon could only say again that he remembered them. His recognition performance was not enhanced by task enactment compared with reading a phrase that described an action task. Task enactment normally boosts remembering (Engelkamp, 1998). Nor did Jon's ERPs show the normal late positive component (LPC) that has been associated with remembering; they did show an earlier negative component (the so-called N400 effect) that has been associated with knowing (Rugg et al., 1998). Jon also claimed to remember general knowledge facts that he knew prior to a laboratory study of how he acquires novel facts, unlike participants in a control group who (correctly) claimed just to know them. Jon did successfully learn quite a few of the novel facts that he knew prior to an unpublished study, albeit at a greatly reduced rate compared with that of the control group. This reduced learning performance reflects Jon's inability to use remembering of the learning episodes as an aid to knowledge acquisition.

At the other extreme, knowledge of an event that has occurred recently but which cannot be remembered also gives rise to noetic awareness and represents a minimal level of encoding in semantic memory. Encoding at this level can be fostered by having very rapid, perceptually oriented study conditions of the sort used by Gregg and Gardiner (1994; see also Gardiner and Gregg, 1997) or by having divided instead of full attention at study (Mangels et al., 2001). Under these conditions, there are at least some effects in memory that occur in knowing instead of remembering.

Shown in **Figure 3** is an example of the size congruency effect in picture recognition memory with either full attention or divided attention at study (Gardiner et al., 2001). Divided attention reduced recognition performance but did not influence the size congruency effect. **Table 4** includes the partitioning of these data between remember and know responses. With full attention, the size congruency effect occurred in remembering, replicating results first reported by Rajaram (1996; see also Yonelinas and Jacoby, 1995).

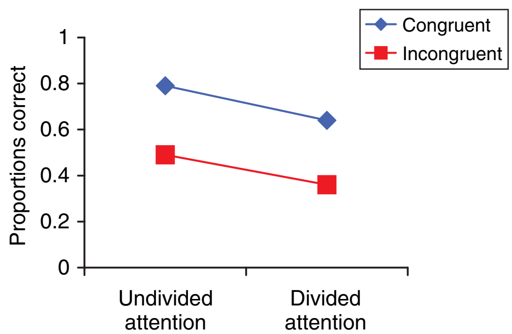


**Figure 3** Effects of attention and picture size congruence on overall recognition (correct 'old' response proportions). Adapted from Gardiner JM, Gregg VH, Mashru R, and Thaman M (2001) Impact of encoding depth on awareness of perceptual effects in recognition memory. *Mem. Cognit.* 29: 433–440, Table 1, with permission from The Psychonomic Society.

**Table 4** Further effects (shown in bold) of some experimental manipulations on remembering and knowing (for correct 'old' response proportions)

| *Manipulations* | *Study/test congruency* | *Remember* | *Know* |
|---|---|---|---|
| Full attention | Same size | **.53** | .26 |
| | Different size | **.37** | .27 |
| Divided attention | Same size | .15 | **.34** |
| | Different size | .12 | **.22** |
| Full attention (with words) | Same voice | **.44** | .31 |
| | Different voice | **.34** | .33 |
| Divided attention (with nonwords) | Same voice | .18 | **.38** |
| | Different voice | .16 | **.28** |
| Longer study time | Same size | **.42** | .14 |
| | Different size | **.32** | .14 |
| Shorter study time | Same size | .22 | **.28** |
| | Different size | .19 | **.18** |

These examples are taken, respectively, from experiments by Gardiner JM, Gregg VH, Mashru R, and Thaman M (2001) Impact of encoding depth on awareness of perceptual effects in recognition memory. *Mem. Cognit.* 29: 433–440; Karayianni I and Gardiner JM (2003) Transferring voice effects in recognition memory from remembering to knowing. *Mem. Cognit.* 31: 1052–1059; and Nega C (2005) Perceptual effects and recollective experience in face recognition. *Exp. Psychol.* 52: 224–231.

With divided attention, however, the effect occurred in knowing. Similar results, also shown in **Table 4**, obtain for congruency of male or female speaker's voice (Karayianni and Gardiner, 2003) and, with a manipulation of study time duration rather than of attention, for facial size congruency (Nega, 2005). For reasons that remain unknown, other similar conditions do not reveal this transfer of effects from one state of awareness to the other. Curran and Hildebrandt (1999), for example, found that although alcohol selectively reduced remembering, the generation effect (better memory for study list words participants generate rather than read) remained in remembering. It did not emerge in knowing.

That following relatively impoverished study conditions some effects occur in knowing instead of in remembering supports the SPI model of relations between semantic and episodic systems (Tulving, 1995). Impoverished encoding conditions reduce the more elaborative and consciously controlled encoding necessary for episodic memory, but do not much affect the more automatic and less consciously controlled encoding sufficient for semantic memory. By the same token, these findings support the distinctiveness/fluency framework (Rajaram, 1996) and confirm that the distinction between conceptual and perceptual processing is orthogonal to the distinction between the two states of awareness, because similar perceptual effects can occur in either state. Impoverished encoding conditions presumably reduce the opportunity for more distinctive processing without much affecting processing fluency.

Another general theoretical issue concerns the relations between consciousness of memory, in the sense of remembering versus knowing, and consciousness of task control, whatever the task may be. It has been rather generally assumed that whereas remembering is consciously controlled, knowing is not. These assumptions have not only been central to dual-process models, according to which recollection is a controlled process and familiarity is an automatic process, but they have also been made in relation to episodic and semantic memory systems. Access to episodic memory usually requires conscious effort, whereas access to semantic memory tends to be automatic (Tulving, 1983).

Conscious control at encoding can easily be manipulated by comparing full with divided attention, as in **Table 4**. Such manipulations are less effective for retrieval in recognition tests but conscious control there can be effectively manipulated by using a response deadline procedure that compares speeded with unspeeded recognition. Because more automatic retrieval is thought to occur more rapidly than consciously controlled retrieval, fast recognition decisions are assumed to be more automatic and slower ones more controlled. The data summarized in **Table 5** show the effects of fast (under 700 ms) compared with slow (over 3000 ms) recognition decisions on voice congruence effects following either full attention or divided attention at encoding. In the preceding examples of results, false alarms, and also guess responses (if included in the paradigm), were omitted, but in **Table 5** the complete results are shown.

With full attention at encoding, the voice congruence effect occurred in remembering, and with divided attention at encoding the effect occurred in knowing, as found by Karayianni and Gardiner (2003). In neither case was the voice congruence effect influenced by response deadline. This suggests that though the state of awareness with which the voice congruence effect is associated depends on the degree of conscious control at encoding, it does not depend on the degree of conscious control at retrieval. That the effect in knowing remained in knowing even with slower more effortful recognition decisions is consistent with

**Table 5** Mean proportions of responses for fast and slow recognition as a function of voice congruence and following full or divided attention at study

| | *Congruent* | | *Incongruent* | | *New items* | |
|---|---|---|---|---|---|---|
| *Attention/response category* | *Fast* | *Slow* | *Fast* | *Slow* | *Fast* | *Slow* |
| ***Full attention*** | | | | | | |
| Old | .48 | .73 | .36 | .61 | .11 | .16 |
| Remember | .29 | .45 | .16 | .28 | .03 | .04 |
| Know | .16 | .24 | .15 | .28 | .05 | .07 |
| Guess | .03 | .04 | .04 | .05 | .03 | .06 |
| ***Divided attention*** | | | | | | |
| Old | .46 | .69 | .36 | .62 | .13 | .17 |
| Remember | .13 | .24 | .13 | .24 | .03 | .03 |
| Know | .31 | .41 | .21 | .31 | .07 | .08 |
| Guess | .02 | .04 | .03 | .07 | .03 | .05 |

Adapted from Gardiner JM, Gregg VH, and Karayianni I (2006b) Recognition memory and awareness: Occurrence of perceptual effects in remembering or in knowing depends on conscious resources at encoding, but not at retrieval. *Mem. Cognit.* 34: 227–239, Tables 2 and 4. with permission from The Psychonomic Society.

Tulving's (1993) coordination hypothesis, according to which however much time and effort goes into the retrieval attempt, the resulting state of awareness cannot exceed the level of awareness achieved at encoding. That the effect in remembering remained in remembering, even with faster more automatic recognition decisions, is consistent with the view that remembering can be more automatic, as well as being more effortful and consciously controlled. Finally, that knowing, as well as remembering, generally increased with slow recognition decisions is consistent with the view that knowing, as well as remembering, can be more effortful and consciously controlled, as well as being more automatic. Similar results were obtained by Konstantinou and Gardiner (2005) in a recognition study of famous faces (see too, Gardiner et al., 1999). There is also evidence that when response times are measured, instead of being manipulated, recognition decisions associated with remember responses are made more rapidly than those associated with know responses (Dewhurst and Conway, 1994; Dewhurst et al., 2006). Those results imply that, if anything, it is remembering that is more automatic and knowing that is more consciously controlled.

There is other evidence that remembering and knowing may both be more consciously controlled, or more automatic, depending on encoding and retrieval conditions, from studies in which word-stem cued recall (e.g., DEF. . . .: What study list word does this remind you of?) is compared with incidental word-stem completion (e.g., DEF. . . .: Complete this word stem with the first word that comes to mind). In such comparisons, generating compared with reading words at study leads to superior recall (the generation effect), but the words that were read at study are more likely to be those that come to mind in incidental word-stem completion (the priming effect). Java (1994; see also Java, 1996) replicated this reversal of the generation effect and showed that both tests gave rise both to remembering and to knowing. Moreover, though the generation effect in recall occurred in remembering, the read superiority effect in incidental word-stem completion was restricted to words participants reported as not being in the study list. Such results underscore the need for a distinction between the voluntary (intended) or involuntary (unintended) retrieval of study list words, as evidenced by the reversal of the generation effect, and awareness of memory, as evidenced by remember and know responses. This distinction between retrieval volition and awareness of memory has been discussed in some detail by Richardson-Klavehn et al. (1996) and it has been supported by the results of other empirical studies (e.g., Richardson-Klavehn and Gardiner, 1996, 1998; see also Richardson-Klavehn et al., 2002).

The guess responses shown in **Table 5** are fairly typical, especially when, as here, the instructions discourage guessing. Guess response rates to study list items have generally been found to be little different from those for unstudied items, that is, false alarms (Gardiner and Conway 1999; Gardiner et al., 2002). Hence, when participants report guessing, they do seem to be guessing. There are also usually more know false alarms than remember false alarms, again as shown in **Table 5**. False alarms are by definition inaccurate with respect to identifying previously studied items but they are not necessarily inaccurate with respect to indicating states of awareness, nor should they be if reports of those states of awareness are valid. It is perfectly natural that participants may have some genuine experiences of remembering and some genuine experiences of knowing when deciding about test items that did not occur in a study list. Moreover, the extent to which people have such genuine experiences will naturally vary depending on experimental conditions.

Experimental conditions have been deliberately designed to manipulate the extent to which people have such 'false' memories, but genuine experiences include those intended to foster illusions of memory. Roediger and McDermott (1995) reintroduced such experimental conditions in revising a converging associates paradigm originally used by Deese (1959). In this paradigm, participants study lists of words that are all highly associated with target associates that are not presented (e.g., study 'bed, rest, awake, tired, dream, . . . etc.,' for the target associate 'sleep'). In one of their experiments, Roediger and McDermott (1995) gave participants either immediate free recall tests or an arithmetic filler task before giving them a recognition test that included the target associate (termed the critical lure) as well as other lure items unrelated to the study lists.

Participants recalled the critical nonpresented word for 55% of the lists, which proportionally approximated the rate of recall for the words from the middle of the studied lists. The recognition results are shown in **Table 6**. The critical lure was recognized to practically the same extent as were the study list words. Moreover, recognition of the critical lure was associated primarily with remember responses, though know responses too were somewhat greater for the critical lure than for other unrelated nonstudied words.

**Table 6** Mean proportions of responses for studied words, critical lures, and nonstudied words

| *Item type and condition* | *Old* | *Remember* | *Know* |
|---|---|---|---|
| Studied | | | |
| Study + recall | .79 | .57 | .22 |
| Study + arithmetic | .65 | .41 | .24 |
| Nonstudied | .11 | .02 | .09 |
| Critical lure | | | |
| Study + recall | .81 | .58 | .23 |
| Study + arithmetic | .72 | .38 | .34 |
| Nonstudied | .16 | .03 | .13 |

Reprinted from Roediger HL and McDermott KB (1995) Creating false memories: Remembering words not presented in lists. *J. Exp. Psychol. Learn. Mem. Cognit.* 21: 803–814, Table 2, with permission from The American Psychological Association.

Such striking illusions of memory have since been replicated many times. For example, Düzel et al. (1997) investigated the ERP correlates of remembering and knowing using the converging associates paradigm. They found that the patterns of neural activity for remembering and knowing when recognizing studied words and when falsely recognizing critical lures were indistinguishable. The patterns of neural activity were predicted by the states of awareness not by the accuracy of the recognition judgment. Schacter et al. (1997a) extended the paradigm by also presenting lists of perceptually similar words (words that all looked and sounded alike). They found that with perceptually rather than conceptually induced false recognition, the recognition of critical lures was mainly associated with knowing, rather than with remembering. And in a long-term diary study, Conway et al. (1996) also found that false recognition of lures that were plausible diary entries (altered or false records of events and thoughts) was associated mainly with knowing, especially for thoughts. Other memory illusions in knowing, as well as in remembering, have been reported (see, e.g., Dewhurst and Hitch, 1997).

Illusions of memory can be understood within an attributional approach to memory (Jacoby et al., 1989). Experiences of remembering or of knowing are attributed to particular circumstances or situations, sometimes correctly, sometimes not. Thus, illusions of memory, and false alarms generally, may reflect genuine experiences of memory that are then misattributed to the prior occurrence in a studied list of the items that gave rise to those experiences. Such attributions implicate source memory and reality monitoring, and they have been widely studied within a source-monitoring framework (Johnson et al., 1993). A number of these studies have used memory characteristics questionnaires to provide a more fine-grained analysis of differences between remembering and knowing, both for veridical and for illusory memories (Mather et al., 1997; Schacter et al., 1997b). In general, remembering when veridical seems characterized by the availability of sharper perceptual detail and sometimes by less affect than when illusory. A multinomial model of multidimensional source information that incorporates remember and know responses has been proposed by Meiser and Broder (2002), who replicated previous findings that memory for source is more accurate with remembering than with knowing (Conway and Dewhurst, 1995; Dewhurst and Hitch, 1999). They also found that source memory for different contextual features was stochastically related for remembering but independent for knowing. Creating an episode that will be remembered involves the binding together of different contextual features, but the occurrence of each of those individual features may be known without retrieving the episode. In a somewhat similar vein, Sikstrom and Gardiner (1997) found that whereas the words that were remembered from the same study list in successive tests of recognition and cued recall (the 'recognition-failure' paradigm) were stochastically related, there was no such relationship between the words that were known in each test. People can also predict which state of awareness they will experience when recognizing items that they cannot recall (Hicks and Marsh, 2002).

There is evidence that remember and know responses are influenced by test–list context. Bodner and Lindsay (2003) found that how much people reported remembering and the relative weighting they assigned to different aspects of what they remembered were affected by whether word lists that had been studied at a medium level of processing were tested along with other words that had been studied at either a shallow or deep level of processing. When asked to report their strongest recollections, the main recollections were of list source (the level of processing), of some thought or association, and of some visual image. The proportions of these different recollections given as the strongest recollection accompanying remember responses varied considerably as a function of test–list context. Importantly, performance in direct tests of memory for source was not influenced by study–test context. These findings support a functional view that places some emphasis on the uses to which mental experiences of memory are put, and how people come to define remembering and knowing under various task demands and conditions, as well as on the experiences as such (see also Whittlesea, 2002a,b).

Clearly, people make decisions about their experiences of memory, but the idea that remembering and knowing just reflect decision making and differ only quantitatively, not qualitatively, is misconceived. This is the claim made in a signal detection model that assumes a single trace strength with different response criteria for remembering and for knowing (Donaldson, 1996; Hirshman and Master, 1997; Hirshman, 1998; Inoue and Bellezza, 1998). This model can simulate dissociative effects between remembering and knowing by assuming that different experimental conditions affect the placement of the response criteria. Bodner and Lindsay (2003) are among others (e.g., Gardiner et al., 1998b) who have strongly criticized this model on the grounds that it provides no explanation as to why the placements of response criteria are affected by different experimental conditions and in different populations in the ways that they are. Nor do changes in criteria provide any account of how such different experiences of consciousness come to mind, only of how, once they have come to mind, decision processes may operate on responses based on them. Moreover, experimental manipulations of response criteria run the risk of invalidating the responses. Participants are given somewhat contradictory instructions when told to respond with very lenient or with very strict response criteria but at the same time only to respond according to the definitions given in **Table 1**. This may be partly why false alarm rates have been exceptionally large in some studies that have manipulated response criteria and why one such study found effects of response criteria on both know and remember responses (Hirshman and Henzler, 1998), another study on know but not remember responses (Strack and Forster, 1995), and other studies only on guess responses (Gardiner et al., 1997, 2002). There is also some evidence of small effects on response criteria depending on whether remember and know responses are given after an old/new responses, or in parallel, that is, remember or know or new. The latter, one-stage procedure, leads to a more lenient response bias (Hicks and Marsh, 1999; Eldridge et al., 2002; Gardiner et al., 2005).

Though studies in which confidence judgments have been directly compared with remember and know responses as, for example, by substituting sure and unsure judgments for those responses, have consistently found that the confidence judgments yield different patterns of results (e.g., Gardiner and Java, 1990; Perfect et al., 1995; Mantyla, 1997; Holmes et al., 1998; Gardiner and Conway, 1999; Rajaram et al., 2002), both Dunn (2004) and Wixted and Stretch (2004) have shown how differences between remember/know responses and sure/unsure judgments are not inconsistent with the signal detection model, which can fit these data too. Wixted and Stretch (2004) suggested that rather than representing a single process, the strength dimension might represent the sum of recollection and familiarity. They also listed various findings that are consistent with this model, such as the finding that in meta-analyses of different experiments, remember and know hit rates and false alarm rates are correlated. But one could list other findings that are inconsistent with this model, which include evidence that remembering and knowing may differ substantially in the absence of any differences in trace strength, as measured from overall recognition scores (Conway et al., 2001; cf. Hirshman and Lanning, 1999) and evidence that the ROC curves predicted by this model have the wrong slope (Rotello et al., 2004).

A two-dimensional signal detection model proposed by Rotello et al. (2004) is more in keeping with Tulving's (1985) original proposal. According to their sum-difference (S) theory (T) of remembering (RE) and (A) knowing (K), both remembering and knowing contribute to the sum of the overall trace strength, on which old-new judgments are based. Remember and know responses, however, are based on a weighted difference between the two contributing dimensions. Rotello et al. showed how STREAK can account for new ROC curves, including those derived not only from confidence in old-new judgments but also confidence *in* remember and know responses (see too, Rotello and Macmillan, 2005).

Word frequency effects in recognition memory have also proved controversial theoretically. The discovery that the superior recognition of low-compared with high-frequency words occurred in remembering, not in knowing (Gardiner and Java, 1990), ruled out earlier suggestions that this effect was due to greater increments in familiarity (Mandler, 1980). Since then, other kinds of dual-process accounts of word frequency effects using the remember-know paradigm have been developed (Guttentag and Carroll, 1997; Joordens and Hockley, 2000; Reder et al., 2000). These accounts are specifically directed at the word-frequency mirror effect, that is, the finding that whereas there are more correct old judgments for low- than for high-frequency words, there are also more incorrect new judgments for high- than for low-frequency words. According to these theories, the low-frequency advantage in correct old judgments arises from their greater distinctiveness in the experimental context, which boosts recollection and hence occurs in remembering. In contrast, the finding of more incorrect new judgments for high- than for low-frequency words is attributed to greater semantic activation from their greater preexperimental familiarity. Hence this effect should occur in knowing. Moreover, for the same reason, old high-frequency words should also give rise to more know responses than the old low-frequency words. Reder et al. (2000) found good support for these predictions, and they developed a computational model (SAC: Source of Activation Confusion) to account for them. This model distinguishes between word or concept nodes and episode nodes, the activation of which respectively gives rise to familiarity and to recollection, hence to know and remember responses. See Diana et al. (2006) for further discussion of this model.

Joordens and Hockley (2000) also proposed a similar dual-process account, though without the aid of a computational model. Some of the effects they found are illustrated in **Table 7**. Furthermore, Gregg et al. (2006) found that with a divided attention task at study there was a high-frequency advantage not simply in the number of know responses (i.e., both hits and false alarms), as found in previous studies, but in their accuracy (i.e., in corrected recognition scores). This outcome suggests that under at least some circumstances that reduce remembering, the high-frequency advantage in knowing can be driven more by experimental than by preexperimental familiarity.

Further support for this kind of dual-process account of word frequency effects was found by Hirshman et al. (2002), who used midazolam to induce amnesia with the assumption that this drug would have larger effects on recollection than familiarity. The effects of the drug were to remove the usual low-frequency advantage in remembering the old words but to leave the high-frequency advantage to both old and new words unaffected, with the result that the traditional word frequency effect – higher hit rates for the low frequency words – was reversed (see also Balota et al., 2002).

**Table 7** Mean proportions of responses for low- and high-frequency words

| | *Old items* | | *New items* | |
|---|---|---|---|---|
| *Response category* | *High freq.* | *Low freq.* | *High freq.* | *Low freq.* |
| Immediate test | | | | |
| Old | .83 | .90 | .12 | .08 |
| Remember | .60 | .68 | .04 | .02 |
| Know | .23 | .22 | .08 | .06 |
| Delayed test | | | | |
| Old | .63 | .68 | .26 | .18 |
| Remember | .36 | .47 | .08 | .06 |
| Know | .27 | .21 | .19 | .12 |

Adapted from Joordens S and Hockley WE (2000) Recollection and familiarity through the looking glass: When old does not mirror new. *J. Exp. Psychol. Learn. Mem. Cognit.* 26: 1534–1555, Table 1, with permission from The American Psychological Association.

However, Malmberg et al. (2004) have shown that these results, and by implication other findings taken to support dual-process accounts, are also consistent with a variety of single-process, retrieving effectively from memory models (Shiffrin and Steyvers, 1997) that, rather like signal detection models and other global models of memory, assume that recognition is based on a continuous random variable that may be conceptualized as trace strength or familiarity. Thus, here too data that seem to support dual-process accounts may also be consistent with single-process accounts, though, as Malmberg et al. (2004) pointed out, that does not necessarily mean that dual-process models are incorrect. There continues to be controversy about the extent to which such effects in remembering and knowing are best explained by dual-process accounts or by global models of memory (see, e.g., Park et al., 2005).

Studies involving amnesic patients have yielded a similar kind of theoretical problem. Yonelinas et al. (1998) reported a convergence of remember-know, process dissociation (Jacoby, 1991) and ROC data from amnesic patients and matched controls and concluded that these data all supported a dual-process account, rather than a single-process one, partly on the grounds that the patients' ROC curves were symmetrical, whereas the ROC curves for the controls were asymmetrical, as is more usual. But there is also evidence that once differences in the strength of memory are taken into account, ROCs for patients and for controls are similar (Wais et al., 2006). Such findings are relevant to debate about the role of the hippocampus with respect to remembering and knowing in amnesic patients and about whether the hippocampus supports both states of awareness or selectively supports remembering, with the implication that other parts of the medial temporal lobe may support knowing. Although there are studies that strongly imply a selective role for the hippocampus in remembering (e.g., Aggleton et al., 2005; Gardiner et al., 2006a), others find that patients with selective hippocampal damage are similarly impaired in both remembering and knowing (e.g., Manns et al., 2003). At the moment, it remains unclear how this important issue will be resolved.

Further evidence relevant to this issue comes from studies of brain imaging in normal adults. For example, in a functional magnetic resonance imaging (fMRI) study Eldridge et al. (2000) showed that the hippocampus is selectively active when recognition is accompanied by remembering but not when it is accompanied by knowing. In another fMRI study, Henson et al. (1999) found several brain regions that were differentially activated when remembering or when knowing, and that greater activation in anterior left prefrontal, left parietal, and posterior cingulate regions was associated with remember responses. Wheeler and Buckner (2004) also used fMRI, and they too found functional dissociations between remembering and knowing. Lateral parietal regions responded preferentially with remembering, whilst other medial regions responded strongly both with remembering and with knowing.

In discussing implications for theories of remembering, Wheeler and Buckner (2004) pointed out that the evidence, particularly from parietal regions, suggests at least a partially shared neural basis for remembering and for knowing. But as well as sharing certain memory-related neural processing with knowing, remembering has additional and distinct neural correlates. This interpretation runs counter to the assumption of independence between recollection and familiarity as conceived in some dual-process models, and it seems more consistent with the SPI model (Tulving, 1995), according to which events are encoded serially into semantic and episodic systems. Moreover, evidence that remembering involves distinct neural processes that lead to the retrieval of the content of qualitatively distinct phenomenal experiences is quite beyond the scope of single-process theories, according to which remembering falls along a continuum of familiarity and is simply a matter of decision criteria or confidence.

Other brain regions that seem crucial for remembering include the frontal lobes. Some studies, though not all, have found correlations between measures of frontal lobe function and the amount of remembering reported (e.g., Parkin and Walter, 1992). Wheeler and Stuss (2003) compared patients with injuries restricted to the frontal lobes that were either centered in the frontal poles or confined to the dorsolateral prefrontal context. Overall recognition performance in the two patient groups was very similar to that in a matched control group. But although patients with the dorsolateral injuries were unimpaired either in remembering or in knowing, patients with polar injuries were selectively impaired in remembering. Some of these results are summarized in **Table 8**. This dissociation links remembering to other cognitive functions that seem to depend on polar regions of the frontal lobes, such as theory of mind and the concept of self, self-monitoring, and planning for the future. These broader implications of remembering were also emphasized by Levine

**Table 8** Mean proportions of responses for patient and control groups

| | *Studied* | | | *Unstudied* | | |
|---|---|---|---|---|---|---|
| *Response category* | *Old* | *Remember* | *Know* | *Old* | *Remember* | *Know* |
| Dorsolateral | .70 | .52 | .18 | .04 | .01 | .03 |
| Polar | .60 | .16 | .44 | .02 | .01 | .01 |
| Patient mean | .65 | .34 | .31 | .03 | .01 | .02 |
| Control mean | .67 | .36 | .31 | .03 | .01 | .02 |

Adapted from Wheeler MA and Stuss DT (2003) Remembering and knowing in patients with frontal lobe injuries. *Cortex* 39: 827–846, Appendix B, with permission from Masson SPA.

et al. (1998; see also Levine, 2000) in their investigation of remembering and knowing in another patient with brain injuries to the frontal cortex, particularly the right ventral frontal lobe. This patient too showed similar levels of recognition performance to that observed in a control group, but with selectively impaired remembering. Levine et al. also found that their patient was significantly impaired in self-regulation and suggest that his behavior generally is driven by generic knowledge in semantic memory, rather than by goals and intentions that arise from a sense of his own identity.

Thus, although there is still a great deal to be learned about the brain mechanisms underlying experiences of remembering or of knowing, it has already become clear that the extended networks likely to be involved are at least partially distinct in critically important ways and in ways that relate the two states of awareness to much broader aspects of cognitive function, especially those related to the sense of self. Other recent studies that converge on this conclusion include those concerned with normal aging (e.g., Bunce and Macready, 2005), during which autonoetic awareness diminishes, and those concerned with autism (e.g., Bowler et al., 2007) and schizophrenia (e.g., Tendolkar et al. 2002; Danion et al. 2003), two disorders that are also associated with reduced autonoetic awareness and, to widely varying extents, an altered sense of self.

## 2.17.7 Theoretical Evaluation

Although all of the theories that have been put forward to account for remembering and knowing help elucidate these states of awareness, none provides an entirely satisfactory account of them. The distinction between episodic and semantic systems is in some respects compelling, and there has to be at least a partially distinct and dissociable neural basis for remembering and knowing, even if it is not yet entirely clear what this basis is. One major problem for this theory concerns the interface between episodic remembering and autobiographical memory (see Conway and Pleydell-Pearce, 2000; see also Rubin et al., 2003), which may be a part of the semantic system that includes not only facts known about oneself but also a more generic kind of remembering and which, indeed, can perhaps simulate remembering. The distinctiveness/fluency framework continues to provide useful guidelines with respect to which variables are likely to influence each state of awareness (e.g., Brandt et al., 2003; Dewhurst et al., 2005) but does not take us very much further. The earlier dual-process models continue to provide a reasonably good account for much of the evidence (see Yonelinas, 2002), but there is other evidence against some of their commonly held assumptions, such as those about conscious control and independence. Other dual-process models have been developed, initially in relation to word frequency effects (e.g., Reder et al., 2000; Diana et al., 2006). The attributional approach and the source-monitoring framework offer a more functional view, but perhaps have limited scope. Signal detection models are overly focused on modeling responses rather than on understanding the states of awareness that give rise to them and, as Dunn (2004) pointed out, the challenge for this approach is to develop more psychologically meaningful accounts.

There has recently been a spate of formal quantitative models. But the increasing technical sophistication and complexity of some of these models and the rather general ability of most of them to provide a reasonably good fit to the data make it increasingly difficult to see how to distinguish between them empirically (see, e.g., Rotello and Macmillan, 2005; Macmillan and Rotello, 2006; Murdock, 2006). Confronted by a plethora of alternative versions of such models, it is hard (despite the claims sometimes made for this approach) to see any great advantage of quantitative modelling over a less mathematically, more conceptually driven approach. Nor should it be forgotten that many of the most important advances made in the last 50 years or so were spearheaded by the introduction and empirical refinement of new concepts, concepts such as those of retrieval, levels of processing, and memory systems.

Remembering and knowing are natural mental phenomena that evolved for some purpose and so have adaptive significance, both for the species and for the individual. Individuals make judgments, reach decisions, and take action on the basis of these states of awareness. So in one sense their true significance, with respect to adaptation and behavior, if not with respect to memory theory, lies in the personal and social uses to which they are put. This is another reason why it has been important to study these states of awareness experimentally and to discover how they are influenced by different conditions and what their neural correlates are. Gaining a better understanding of remembering and knowing theoretically will depend on further evidence that links these states of awareness not only with behavior but also with the brain. The most promising new cognitive theories are likely to be those that have some conceptual correspondence with what is known about neuroanatomical function (see Roediger et al., 2007), and no theoretical assumptions that seem inconsistent with neuroanatomical function should be seriously entertained.

## References


Aggleton JP, Vann SD, Denby C, et al. (2005) Sparing of the familiarity component of recognition memory in a patient with hippocampal pathology. *Neuropsychologia* 43: 1810–1843.

Baddeley A, Vargha-Khadem F, and Mishkin M (2001) Preserved recognition in a case of developmental amnesia: Implications for the acquisition of semantic memory? *J. Cognit. Neurosci.* 13: 357–369.

Balota DA, Burgess GC, Cortese MJ, and Adams DR (2002) The word-frequency mirror effect in young, old, and early-stage Alzheimer's disease: Evidence for two processes in episodic recognition performance. *J. Mem. Lang.* 46: 199–226.

Blaxton TA and Theodore WH (1997) The role of the temporal lobes in recognizing visuo-spatial materials: Remembering versus knowing. *Brain Cogn.* 35: 5–25.

Bodner GE and Lindsay DS (2003) Remembering and knowing in context. *J. Mem. Lang.* 48: 563–580.

Bowler DM, Gardiner JM, and Grice S (2000) Episodic memory and remembering in adults with Asperger's syndrome. *J. Autism Dev. Disord.* 30: 305–316.

Bowler DM, Gardiner JM, and Gaigg SB (2007) Factors affecting conscious awareness in the recollective experience of adults with Asperger's syndrome. *Conscious. Cognit.* 16: 124–143.

Brandt KR, Macrae CN, Schloerscheidt AM, and Mile AB (2003) Remembering or knowing others? Person recognition and recollective experience. *Memory* 11: 89–100.

Bunce D and Macready A (2005) Processing speed, executive function, and age differences in remembering and knowing. *Q. J. Exp. Psychol.* 58A: 155–168.

Conway MA, Collins AF, Gathercole SE, and Anderson SJ (1996) Recollections of true and false autobiographical memories. *J. Exp. Psychol. Gen.* 125: 69–95.

Conway MA and Dewhurst SA (1995) Remembering, familiarity, and source monitoring. *Q. J. Exp. Psychol.* 48A: 125–140.

Conway MA, Dewhurst SA, Pearson N, and Sapute A (2001) The self and recollection reconsidered: How a 'failure to replicate' failed and why trace strength accounts of recollection are untenable. *Appl. Cogn. Psychol.* 15: 673–686.

Conway MA, Gardiner JM, Perfect TJ, Anderson SJ, and Cohen GM (1997) Changes in memory awareness during learning: The acquisition of knowledge by psychology undergraduates. *J. Exp. Psychol. Gen.* 126: 393–413.

Conway MA and Pleydell-Pearce CW (2000) The construction of autobiographical memories in the self-memory system. *Psychol. Rev.* 107: 261–288.

Curran HV, Gardiner JM, Java RI, and Allen D (1993) Effects of lorazepam upon recollective experience in recognition memory. *Psychopharmacology* 110: 374–378.

Curran HV and Hildebrandt M (1999) Dissociative effects of alcohol on recollective experience. *Conscious. Cognit.* 8: 497–509.

Dalla Barba G (1997) Recognition memory and recollective experience in Alzheimer's disease. *Memory* 5: 657–672.

Danion JM, Kazes M, Huron C, and Karchouni N (2003) Do patients with schizophrenia consciously recollect emotional events better than neutral events? *Am. J. Psychiatry* 160: 1879–1881.

Danion JM, Rizzo L, and Bruant A (1999) Functional mechanisms underlying impaired recognition memory and conscious awareness in patients with schizophrenia. *Arch. Gen. Psychiatry* 56: 639–648.

Deese J (1959) On the prediction of occurrence of particular verbal intrusions in immediate recall. *J. Exp. Psychol.* 58: 17–22.

Dewhurst SA and Anderson SJ (1999) Effects of exact and category repetition in true and false recognition memory. *Mem. Cognit.* 27: 665–673.

Dewhurst SA and Conway MA (1994) Pictures, images, and recollective experience. *J. Exp. Psychol. Learn. Mem. Cognit.* 20: 1088–1098.

Dewhurst SA, Hay DC, and Wickham LHV (2005) Distinctiveness, typicality, and recollective experience in face recognition: A principal components analysis. *Psychol. Bull. Rev.* 12: 1032–1037.

Dewhurst SA and Hitch G (1997) Illusions of familiarity caused by cohort activation. *Psychol. Bull. Rev.* 4: 566–571.

Dewhurst SA and Hitch G (1999) Cognitive effort and recollective experience in recognition memory. *Memory* 7: 129–146.

Dewhurst SA, Holmes SJ, Brandt KR, and Dean GM (2006) Measuring the speed of the conscious components of recognition memory: Remembering is faster than knowing. *Conscious. Cognit.* 15: 147–162.

Diana RA, Reder LM, Arndt A, and Park H (2006) Models of recognition: A review of arguments in favor of a dual-process account. *Psychol. Bull. Rev.* 13: 1–21.

Donaldson W (1996) The role of decision processes in remembering and knowing. *Mem. Cognit.* 24: 523–533.

Dunn JC (2004) Remember-know: A matter of confidence. *Psychol. Rev.* 111.

Düzel E, Yonelinas AP, Mangun GR, Heinze H-J, and Tulving E (1997) Event-related brain potential correlates of two states of conscious awareness in memory. *Proc. Nat. Acad. Sci.* 94: 5973–5978.
Eldridge LL, Knowlton BJ, Furmanski CS, Bookheimer SY, and Engel SA (2000) Remembering episodes: A selective role for the hippocampus during retrieval. *Nat. Neurosci.* 3: 1149–1153.
Eldridge LL, Sarfatti S, and Knowlton BJ (2002) The effect of testing procedure on remember-know judgments. *Psychol. Bull. Rev.* 9: 139–145.
Engelkamp J (1998) *Memory for Actions*. Hove, UK: Psychology Press.
Gardiner JM (1988) Functional aspects of recollective experience. *Mem. Cognit.* 16: 309–313.
Gardiner JM (2001) Episodic memory and autonoetic consciousness: A first-person approach. *Philos. Trans. R. Soc. Lond. B* 356: 1351–1361.
Gardiner JM, Brandt KR, Vargha-Khadem F, Baddeley A, and Mishkin M (2006a) Effects of level of processing but not of task enactment on recognition memory in a case of developmental amnesia. *Cognit. Neuropsychol.* 23: 930–948.
Gardiner JM and Conway MA (1999) Levels of awareness and varieties of experience. In: Challis BH and Velichkovsy BM (eds.) *Stratification of Consciousness and Cognition*, pp. 237–254. Amsterdam/Philadelphia: Benjamin.
Gardiner JM and Gregg VH (1997) Recognition memory with little or no remembering: Implications for a detection model. *Psychol. Bull. Rev.* 4: 474–479.
Gardiner JM, Gregg VH, Mashru R, and Thaman M (2001) Impact of encoding depth on awareness of perceptual effects in recognition memory. *Mem. Cognit.* 29: 433–440.
Gardiner JM, Gregg VH, and Karayianni I (2006b) Recognition memory and awareness: Occurrence of perceptual effects in remembering or in knowing depends on conscious resources at encoding, but not at retrieval. *Mem. Cognit.* 34: 227–239.
Gardiner JM and Java RI (1990) Recollective experience in word and nonword recognition. *Mem. Cognit.* 18: 23–30.
Gardiner JM, Java RI, and Richardson-Klavehn A (1996) How levels of processing really influence awareness in recognition memory. *Can. J. Psychol.* 50: 114–122.
Gardiner JM, Konstantinou I, Karayianni I, and Gregg VH (2005) Memory awareness following speeded compared with unspeeded picture recognition. *Exp. Psychol.* 52: 140–149.
Gardiner JM and Parkin AJ (1990) Attention and recollective experience in recognition memory. *Mem. Cognit.* 18: 579–583.
Gardiner JM and Radomski E (1999) Awareness of recognition memory for Polish and English folk songs in Polish and English folk. *Memory* 7: 461–470.
Gardiner JM, Ramponi C, and Richardson-Klavehn A (1998a) Experiences of remembering, knowing, and guessing. *Conscious. Cognit.* 7: 1–26.
Gardiner JM, Ramponi C, and Richardson-Klavehn A (1999) Response deadline and subjective awareness in recognition memory. *Conscious. Cognit.* 8: 484–496.
Gardiner JM, Ramponi C, and Richardson-Klavehn A (2002) Recognition memory and decision processes: A meta-analysis of remember, know, and guess responses. *Memory* 10: 83–98.
Gardiner JM and Richardson-Klavehn A (2000) Remembering and knowing. In: Tulving E and Craik FIM (eds.) *Handbook of Memory*, pp. 229–244. Oxford: Oxford University Press.
Gardiner JM, Richardson-Klavehn A, and Ramponi C (1997) On reporting recollective experiences and "direct access to memory systems." *Psychol. Sci.* 8: 391–394.
Gardiner JM, Richardson-Klavehn A, and Ramponi C (1998b) Limitations of the signal detection model of the remember-know paradigm: A reply to Hirshman. *Conscious. Cognit.* 7: 285–288.
Greenfield S (1997) *The Human Brain: A Guided Tour*. London: Weidenfield and Nicolson.
Gregg VH and Gardiner JM (1994) Recognition memory and awareness: A large effect of study-test modalities on "know" responses following a highly perceptual orienting task. *Eur. J. Cognit. Psychol.* 6: 137–147.
Gregg VH, Gardiner JM, Karayianni I, and Konstantinou I (2006) Recognition memory and awareness: A high-frequency advantage in the accuracy of knowing. *Memory* 14: 265–275.
Guttentag RE and Carroll D (1997) Recollection-based recognition: Word frequency effects. *J. Mem. Lang.* 37: 502–516.
Henson RNA, Rugg MD, Shallice T, Josephs O, and Dolan RJ (1999) Recollection and familiarity in recognition memory: An event-related functional magnetic resonance imaging study. *J. Neurosci.* 19: 3962–3972.
Herbert DMB and Burt JS (2001) Memory awareness and schematization: Learning in the university context. *App. Cognit. Psychol.* 15: 617–637.
Hicks JL and Marsh RL (1999) Remember-know judgments can depend on how memory is tested. *Psychol. Bull. Rev.* 6: 117–122.
Hicks JL and Marsh RL (2002) On predicting the future states of awareness for recognition of unrecallable items. *Mem. Cognit.* 30: 60–66.
Higham PA and Vokey JR (2004) Illusory recollection and dual-process models of recognition memory. *Q. J. Exp. Psychol.* 57A: 714–744.
Hirshman E (1998) On the utility of the signal-detection model of the remember-know paradigm. *Conscious. Cognit.* 7: 103–107.
Hirshman E and Henzler A (1998) The role of decision processes in conscious recollection. *Psychol. Sci.* 9: 61–65.
Hirshman E, Fisher J, Henthorn T, Arndt J, and Passannante A (2002) Midazolam amnesia and dual-process models of the word-frequency mirror effect. *J. Mem. Lang.* 47: 499–516.
Hirshman E and Lanning K (1999) Is there a special association between self judgments and conscious recollection? *App. Cognit. Psychol.* 13: 29–42.
Hirshman E and Master S (1997) Modeling the conscious correlates of recognition memory: Reflections on the remember/know paradigm. *Mem. Cognit.* 25: 345–351.
Holmes JB, Waters HS, and Rajaram S (1998) The phenomenology of false memories: Episodic content and confidence. *J. Exp. Psychol. Learn. Mem Cognit.* 24: 1026–1040.
Huron C, Danion JM, Giacomoni F, Grange D, Robert P, and Rizzo L (1995) Impairment of recognition memory with, but not without, conscious recollection in schizophrenia. *Am. J. Psychiatry* 152: 1737–1742.
Inoue C and Bellezza FS (1998) The detection model of recognition using know and remember judgments. *Mem. Cognit.* 26: 299–308.
Jacoby LL (1991) A process-dissociation framework: Separating automatic from intentional uses of memory. *J. Mem. Lang.* 30: 513–541.
Jacoby LL, Kelley CM, and Dywan J (1989) Memory attributions. In: Roediger HL and Craik FIM (eds.) *Varieties of Memory and Consciousness: Essays in Honor of Endel Tulving*, pp. 391–422. Hillsdale, NJ: Erlbaum.
Jacoby LL, Yonelinas AP, and Jennings JM (1997) The relation between conscious and unconscious (automatic) influences: A declaration of independence. In: Cohen JD and Schooler JW (eds.) *Scientific Approaches to the Question of Consciousness*, pp. 13–47. Hillsdale, NJ: Erlbaum.
Java RI (1994) States of awareness following word stem completion. *Eur. J. Cognit. Psychol.* 6: 77–92.
Java RI (1996) Effects of age on state of awareness following implicit and explicit word-association tasks. *Psychol. Aging* 11: 108–111.

Johnson MC, Hashtroudi S, and Lindsay DS (1993) Source monitoring. *Psychol. Bull.* 114: 3–28.

Jones TC and Roediger HL (1995) The experiential basis of serial position effects. *Eur. J. Cognit. Psychol.* 7: 65–80.

Joordens S and Hockley WE (2000) Recollection and familiarity through the looking glass: When old does not mirror new. *J. Exp. Psychol. Learn. Mem. Cognit.* 26: 1534–1555.

Karayianni I and Gardiner JM (2003) Transferring voice effects in recognition memory from remembering to knowing. *Mem. Cognit.* 31: 1052–1059.

Knowlton BJ and Squire LR (1995) Remembering and knowing: Two different expressions of declarative memory. *J. Exp. Psychol. Learn. Mem. Cognit.* 21: 699–710.

Konstantinou I and Gardiner JM (2005) Conscious control and memory awareness when recognising famous faces. *Memory* 13: 449–457.

LeComte DC (1995) Recollective experience in the revelation effect: Separating the contributions of recollection and familiarity. *Mem. Cognit.* 23: 324–334.

Levine B (2000) Self-regulation and autonoetic consciousness. In: Tulving E (ed.). *Memory, Consciousness, and the Brain: The Tallinn Conference*, pp. 200–214. Philadelphia: Psychology Press.

Levine B, Black SE, Cabeza R, et al. (1998) Episodic memory and the self in a case of isolated retrograde amnesia. *Brain* 121: 1951–1973.

Macken WJ and Hampson P (1993) Integration, elaboration, and recollective experience. *Irish J. Psychol.* 14: 279–285.

Macmillan NA and Rotello CM (2006) Deciding about decision models of remember and know judgments: A reply to Murdock. *Psychol. Rev.* 113: 657–665.

Macmillan NA, Rotello CM, and Verde MF (2005) On the importance of models in interpreting remember-know experiments: Comments on Gardiner et al.'s (2002) meta-analysis. *Memory* 13: 607–621.

Malmberg KJ, Zeelenberg R, and Shiffrin RM (2004) Turning up the noise or turning down the volume? On the nature of the impairment of episodic recognition memory by midazolam. *J. Exp. Psychol. Learn. Mem. Cognit.* 30: 540–549.

Mandler GA (1980) Recognizing: The judgment of previous occurrence. *Psychol. Rev.* 87: 252–271.

Mangels JA, Picton TW, and Craik FIM (2001) Attention and successful episodic encoding: An event-related potential study. *Cognit. Brain Res.* 11: 77–95.

Manns JR, Hopkins RO, Reed JM, Kitchener EG, and Squire LR (2003) Recognition memory and the human hippocampus. *Neuron* 37: 171–180.

Mantyla T (1993) Knowing but not remembering: Adult age differences in recollective experience. *Mem. Cognit.* 221: 379–388.

Mantyla T (1997) Recollections of faces: Remembering differences and knowing similarities. *J. Exp. Psychol. Learn. Mem. Cognit.* 23: 1203–1216.

Mantyla T and Raudsepp J (1996) Recollective experience following the suppression of focal attention. *Eur. J. Cognit. Psychol.* 8: 195–203.

Mather M, Henkel LA, and Johnson MK (1997) Evaluating characteristics of false memories: Remember/know judgments and memory characteristics questionnaire compared. *Mem. Cognit.* 25: 826–837.

Mayr E (1982) *The Growth of Biological Thought: Diversity, Evolution, and Inheritance*. Cambridge, MA: Harvard University Press.

Meiser T and Broder A (2002) Memory for multidimensional source information. *J. Exp. Psychol. Learn. Mem. Cognit.* 28: 116–137.

Mogg K, Gardiner JM, Stavrou A, and Golombok SE (1992) Recollective experience and recognition memory for threat in clinical anxiety states. *Bull. Psychon. Soc.* 30: 109–112.

Murdock BB (2006) Decision-making models of remember-know judgments: Comments on Rotello, Macmillan, and Reeder (2004). *Psychol. Rev.* 113: 648–656.

Nega C (2005) Perceptual effects and recollective experience in face recognition. *Exp. Psychol.* 52: 224–231.

Ochsner KN (2000) Are affective events richly recollected or simply familiar? The experience and process of recognizing feelings past. *J. Exp. Psychol. Gen.* 129: 242–261.

Park H, Reder LM, and Dickison D (2005) The effects of word frequency and similarity on recognition judgments: The role of recollection. *J. Exp. Psychol. Learn. Mem. Cognit.* 31: 568–578.

Parkin AJ and Russo R (1993) On the origin of functional differences in recollective experience. *Memory* 1: 231–237.

Parkin A and Walter B (1992) Recollective experience, normal aging, and frontal dysfunction. *Psychol. Aging* 7: 290–298.

Perfect TJ, Williams RB, and Anderton-Brown C (1995) Age differences in reported recollective experience are due to encoding effects, not response bias. *Memory* 3: 169–186.

Rajaram S (1993) Remembering and knowing: Two means of access to the personal past. *Mem. Cognit.* 21: 89–102.

Rajaram S (1996) Perceptual effects on remembering: Recollective processes in picture recognition memory. *J. Exp. Psychol. Learn. Mem. Cognit.* 22: 365–377.

Rajaram S (1998) Conceptual and perceptual effects on remembering: The role of salience/distinctiveness. *Psychol. Bull. Rev.* 5: 71–78.

Rajaram S (1999) Assessing the nature of retrieval experience: Advances and challenges. In: Challis BH and Velichkovsy BM (eds.) *Stratification of Consciousness and Cognition*, pp. 255–275. Amsterdam/Philadelphia: Benjamin.

Rajaram S and Geraci L (2000) Conceptual fluency selectively influences knowing. *J. Exp. Psychol. Learn. Mem. Cognit.* 26: 1070–1074.

Rajaram S, Hamilton M, and Bolton A (2002) Distinguishing states of awareness from confidence during retrieval: Evidence from amnesia. *Cogn. Affect. Behav. Neurosci.* 2: 227–235.

Reder LM, Nhouyvanisvong A, Schunn CD, Ayers MS, Angstadt P, and Hiraki K (2000) A mechanistic account of the mirror effect for word frequency: A computational model of remember-know judgments in a continuous recognition paradigm. *J. Exp. Psychol. Learn. Mem. Cognit.* 26: 294–320.

Richardson-Klavehn A and Gardiner JM (1996) Cross-modality priming in stem completion reflects conscious memory, but not voluntary memory. *Psychol. Bull. Rev.* 3: 238–244.

Richardson-Klavehn A and Gardiner JM (1998) Depth-of-processing effects on priming in stem completion: Tests of the voluntary-contamination, conceptual-processing, and lexical-processing hypotheses. *J. Exp. Psychol. Learn. Mem. Cognit.* 24: 593–609.

Richardson-Klavehn A, Gardiner JM, and Java RI (1996) Memory: Task dissociations, process dissociations, and dissociations of consciousness. In: Underwood GF (ed.) *Implicit Cognition*, pp. 85–155. Oxford, UK: Oxford University Press.

Richardson-Klavehn A, Gardiner JM, and Ramponi C (2002) Level of processing and the process-dissociation procedure: Elusiveness of null effects on estimates of automatic retrieval. *Memory* 10: 349–364.

Roediger HL, Dudai Y, and Fitzpatrick SM (eds.) (2007) *The Science of Memory: Concepts.* New York: Oxford University Press.

Roediger HL and McDermott KB (1995) Creating false memories: Remembering words not presented in lists. *J. Exp. Psychol. Learn. Mem. Cognit.* 21: 803–814.

Roediger HL, Weldon MS, and Challis BH (1989) Explaining dissociations between implicit and explicit measures of retention: A processing account. In: Roediger HL and Craik

FIM (eds.) *Varieties of Memory and Consciousness: Essays in Honor of Endel Tulving*, pp. 3–41. Hillsdale, NJ: Erlbaum.
Rotello CM and Macmillan NA (2005) Remember-know models as decision strategies in two experimental paradigms. *J. Mem. Lang.* 12: 865–873.
Rotello CM, Macmillan NA, and Reeder JA (2004) Sum-difference theory of remembering and knowing: A two-dimensional detection theory model. *Psychol. Rev.* 111: 588–616.
Rubin DC, Schrauf RW, and Greenberg DL (2003) Belief and recollection of autobiographical memories. *Mem. Cognit.* 31: 887–901.
Rugg MD, Schloerscheidt AM, and Mark RE (1998) An electrophysiological comparison of two indices of recollection. *J. Mem. Lang.* 39: 47–69.
Schacter DL, Koutstaal W, Johnson MK, Gross MS, and Angell KE (1997a) False recollection induced by photographs: A comparison of older and younger adults. *Psychol. Aging* 12: 203–215.
Schacter DL, Verfaille M, and Anes MD (1997b) Illusory memories in amnesic patients: Conceptual and perceptual false recognition. *Neuropsychology* 11: 331–342.
Searle JR (1997) *The Mystery of Consciousness*. New York: New York Review of Books.
Shiffrin RM and Steyvers M (1997) A model for recognition memory: REM-retrieving effectively from memory. *Psychol. Bull. Rev.* 4: 145–166.
Sikstrom SP and Gardiner JM (1997) Remembering, knowing, and the Tulving-Wiseman law. *Eur. J. Cognit. Psychol.* 9: 167–185.
Strack F and Forster J (1995) Reporting recollective experiences: Direct access to memory systems? *Psychol. Sci.* 6: 352–358.
Tendolkar I, Ruhrmann S, Brockhaus A, Pukrop R, and Klosterkotter J (2002) Remembering or knowing: Electrophysiological evidence for an episodic memory deficit in schizophrenia. *Psychol. Med.* 32: 1261–1271.
Tulving E (1983) *Elements of Episodic Memory*. New York: Oxford University Press.
Tulving E (1985) Memory and consciousness. *Can. Psychol.* 26: 1–12.
Tulving E (1993) Varieties of consciousness and levels of awareness in memory. In: Baddeley A and Weiskrantz L (eds.) *Attention, Selection, Awareness and Control: A Tribute to Donald Broadbent*, pp. 283–299. London: Oxford University Press.
Tulving E (1995) Organization of memory: Quo vadis? In: Gazzaniga MS (ed.) *The Cognitive Neurosciences*, pp. 839–847. Cambridge, MA: MIT Press.
Tulving E (2002) Episodic memory: From mind to brain. *Ann. Rev. Psychol.* 53: 1–25.
Vargha-Khadem F, Gadian DG, Watkins KE, Connelly A, Van Paesschen W, and Mishkin M (1997) Differential effects of early hippocampal pathology on episodic and semantic memory. *Science* 277: 376–380.
Wais PE, Wixted J, Hopkins RO, and Squire LR (2006) The hippocampus supports both the recollection and the familiarity components of recognition memory. *Neuron* 49: 459–466.
Wheeler MA and Stuss DT (2003) Remembering and knowing in patients with frontal lobe injuries. *Cortex* 39: 827–846.
Wheeler ME and Buckner RL (2004) Functional-anatomic correlates of remembering and knowing. *Neuroimage* 21: 1337–1349.
Whittlesea BWA (2002a) False memory and the discrepancy-attribution hypothesis: The prototype-familiarity illusion. *J. Exp. Psychol. Gen.* 131: 96–115.
Whittlesea BWA (2002b) Two routes to remembering (and another to remembering NOT). *J. Exp. Psychol. Gen.* 131: 325–348.
Wixted JT and Stretch V (2004) In defence of the signal-detection interpretation of remember/know judgments. *Psychol. Bull. Rev.* 11: 616–641.
Yonelinas AP (2002) The nature of recollection and familiarity: A review of 30 years of research. *J. Mem. Lang.* 46: 441–517.
Yonelinas AP and Jacoby LL (1995) The relation between remembering and knowing as bases for recognition: Effects of size congruence. *J. Mem. Lang.* 34: 622–643.
Yonelinas AP, Kroll NEA, Dobbins I, Lazzara M, and Knight RT (1998) Recollection and familiarity deficits in amnesia: Convergence of remember-know, process dissociation, and receiver operating characteristic data. *Neuropsychology* 12: 323–339.

# 2.18 Controlled Processes in Voluntary Remembering

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## 2.18.1 Introduction

The focus of this chapter is on voluntary remembering, in which memories are retrieved through a deliberate, goal-directed search process. Voluntary remembering occurs either in response to an external query or to a query that is generated internally by the person, usually in order to achieve some higher-order goal. For example, a person may try to recall the name of a person, to answer an exam question, or to recount an entire episode to a friend.

This type of remembering can be contrasted with involuntary memory, in which past events come to mind spontaneously and automatically, without any conscious intention to conjure them up. Involuntary memory often occurs during routine daily activity, without any apparent cue (Berntsen, 1996, 1998; Kvavilashvili and Mandler, 2004). An important subclass of involuntary memory that has received special attention is that of intrusive memories. Such memories, typically of traumatic events, occur not only in the absence of an intention to retrieve the events but also against the person's will (Koutstaal and Schacter, 1997; McNally, 1998). Intrusive memories reflect a failure of control over retrieval, because the person is unable to prevent these memories from arising, or fails to terminate them once they arise.

Although we concentrate here on voluntary remembering, we stress that the distinction between voluntary and involuntary memory processes is not sharp, and that any particular act of remembering may involve a mixture of these types of processes. For example, during the deliberate scrutinizing of one's memory for a particular detail, various memory fragments may suggest themselves, diverting the search in new directions. Sometimes, such fragments may even 'intrude' against the rememberer's will, blocking access to other, desired pieces of information.

## 2.18.2 Processes Involved in Remembering

We begin by outlining some general memory principles. In particular, we discuss (1) the role of retrieval cues and retrieval-encoding interactions in determining the accessibility of stored information and (2) the role of metamemory processes in monitoring and controlling the retrieval and reporting of that information. We then integrate these elements within a schematic framework that will guide a more detailed treatment of controlled processes in remembering.

### 2.18.2.1 Retrieval Cues and Retrieval-Encoding Interactions

The amount of information stored in memory exceeds by far the amount of information that can be accessed at any given point in time. In the terminology introduced by Tulving and Pearlstone (1966), much more information is *available* in memory than is *accessible* at any moment. Thus, although we may momentarily fail to retrieve the name of an acquaintance, we may still be able to recall it on some later occasion or recognize it from among several alternatives. The discrepancy between the availability of information and its accessibility to consciousness testifies to the critical role of retrieval processes in bringing stored information to mind (*See* Chapter 2.16; Roediger, 1999).

What prevents all of the available information from being accessed? What is the process by which people search for and recollect stored information from long-term memory?

Tulving (1983) promoted the now-accepted idea that memory is a joint product of stored memory traces and the cues that are present when retrieval is carried out. Thus, given the same conditions of study, retrieval success can vary greatly depending on the conditions of testing. For example, memory is generally better under cued than under uncued recall testing (Tulving and Pearlstone, 1966). The conditions that instigate retrieval often provide many useful retrieval cues. In externally posed queries, some of the cues can be found in the query itself, whereas others may be available in the more general retrieval context. Even when these cues are not sufficient to directly elicit the target item, they can help delimit the memory regions in which that item is likely to be found.

Cues differ considerably in their effectiveness for aiding retrieval. Research examining the effectiveness of extralist words in prompting the recall of studied words (Nelson et al., 2005) indicates that retrieval success varies with a large number of associative properties of the cue and of the target. For example, the larger the number of words that a cue word elicits in word association norms, the lower its effectiveness in facilitating the retrieval of a studied word. The most effective cues for retrieving an event are personal cues associated with the encoding of that event, because these cues are well integrated into the memory trace of the event (e.g., Mantyla, 1986). Many standard mnemonic techniques have people encode the target information together with specific cues that can later be used to prompt retrieval.

In a landmark article, Tulving and Thomson (1973) formulated the *encoding specificity* principle, which states that a cue presented during testing will be effective in aiding retrieval to the extent that it has been encoded together with the solicited memory target at study. A large amount of research has provided evidence for this principle (Tulving, 1983). It has also been extended in the form of the more general principle of *transfer-appropriate processing,* according to which retrieval is effective to the extent that the processing that occurs during retrieval reinstates the processing that took place during encoding (Kolers and Roediger, 1984; Srinivas et al., 1998).

In line with these principles, retrieval efficiency depends on the extent to which the testing conditions reinstate the overall conditions of study. Thus, retrieval is *context dependent,* in that memory is best when testing occurs in the same physical environment in which learning took place. For example, Godden and Baddeley (1975) found that divers who studied a list of words, either on land or underwater, performed better when tested in the same environment as at study rather than in the other environment. Participants have also been found to recall a larger number of words when tested in the same room in which they studied the words than when tested in a different room (Smith et al., 1978). Context-dependent effects are more likely when the environmental contexts differ substantially and when participants deliberately associate the studied material with features of the study environment (Smith and Vela, 2001). These effects are generally obtained for recall but not for recognition (Eich, 1985), suggesting that context reinstatement specifically facilitates retrieval.

Similar evidence exists for the state dependency of memory, indicating that memory performance is best when learning and testing occur under the same internal state. For example, what participants learn while drunk, they remember better while drunk than while sober, and vice versa (Goodwin et al., 1969). A similar pattern has been observed for the effects of marijuana (Eich et al., 1975) and mood (Eich and Metcalfe, 1989). Like context dependence, state-dependent memory benefits are more clearly observed for free recall than for recognition or cued recall (Eich, 1980).

### 2.18.2.2 Metacognitive Monitoring and Control Processes

Much of the work on the effects of cueing and retrieval-encoding interactions has been conducted within a conceptual framework that views the rememberer as a passive conduit through which information flows. For example, the work reviewed in the previous section has mainly emphasized the automatic effects of external and internal retrieval cues and retrieval-encoding interactions on memory performance. In recent years, however, there has been an increased emphasis on the active role of the rememberer in strategically regulating the process of remembering. This new emphasis is most prominent in the area of metacognition research, in which monitoring and control processes have been shown to play a critical role throughout the various phases of remembering (Barnes et al., 1999; Koriat, 2007): They are involved in deciding whether to initiate a memory search, what type of search and retrieval process to use, where in memory to search, when to terminate the search, whether or not to report the retrieved information, and at what level of precision or coarseness to report it. Such decision processes are integral components of remembering – influencing its course and the quality of its products. Traditional memory research has generally avoided the investigation of rememberer-controlled memory processes, perhaps because the operation of these processes was seen to conflict with the desire to achieve strict experimental control (Nelson and Narens, 1994; Koriat and Goldsmith, 1996a).

In the following section, we introduce a schematic framework to help identify and conceptualize the memory and metamemory processes involved in remembering, taking into account the critical role of retrieval cues and encoding-retrieval interactions, just described. This framework will guide the discussion of controlled processes in remembering throughout the remainder of this chapter.

### 2.18.2.3 A Schematic Framework

Let us consider the simple case in which a person is presented with a memory query in the form of a question. How does one come up with an answer to that query? Figure 1 presents a schematic framework for the processes involved in remembering. Broadly speaking, we first *search* our memory for the best answer we can find and then decide whether and how we want to *report* it. For simplicity, we describe the processes involved in remembering sequentially, although we assume that they are actually somewhat overlapping and parallel.

Memory search is conceptualized here as an iterative process. First, the rememberer sets parameters that define what he or she is looking for in memory and determine broadly the manner in which that information will be accessed. The search parameters include cues that are provided explicitly in the memory query and additional cues that are available in the overall retrieval context or generated by the rememberer in response to the query (cf. target descriptions in Norman and Bobrow, 1979). The parameters also include search criteria that define what will be considered a satisfactory answer to the query (verification criteria in Norman and Bobrow, 1979) and a rough metacognitive assessment of the accessibility of the answer. Another important parameter is the search strategy that will be invoked.

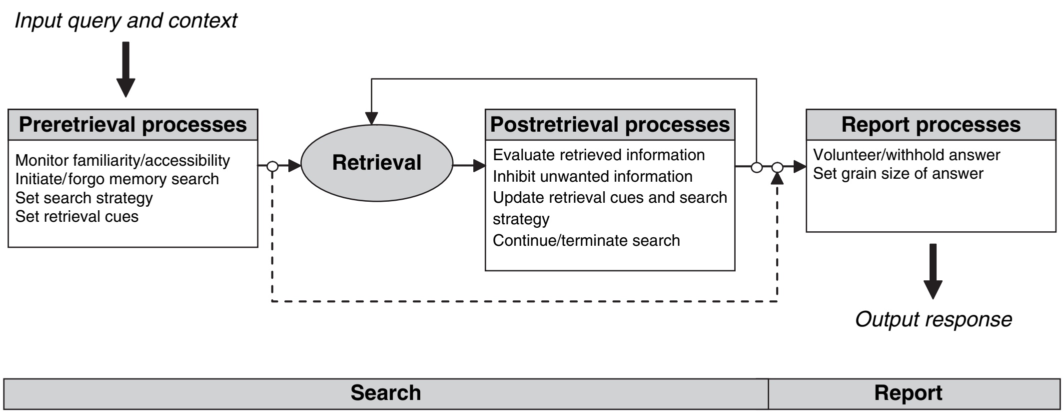


**Figure 1** A schematic framework for the memory and metamemory processes involved in remembering (dashed line represents the decision to forgo a memory search).

These parameters determine the initial course of the retrieval of information from memory, as well as whether retrieval will be attempted at all. Because it appears to capture much of the mainstream thinking about memory retrieval, we adopt Tulving's (1983) concept of *ecphory* to describe the specific operation of retrieval during a (sometimes) more prolonged memory search process. According to this concept, when an item of information is encoded, a memory trace (engram) is created that includes not only the item itself but also other information from the cognitive context at the time of encoding (related thoughts, for instance). During retrieval, parts of the encoded engram combine synergistically with the search cues to produce "a conscious memory of particular aspects of the original event" (Tulving, 1976, p. 40). Consequently, the retrieved (ecphoric) information that comes to mind is actually a combination of the search cues and stored information. We assume that, although rememberers cannot control the process of ecphory itself, which is conceptualized here as an automatic, ballistic operation (Moscovitch, 1994; Guynn, 2003; but see Naveh-Benjamin et al., 2000), they can influence the outcome of a memory search by controlling the parameters that are used for the individual operations of retrieval and the overall strategy that determines the number and nature of these operations.

A very different conception of remembering is offered by the reconstructive approach (Bartlett, 1932; Neisser, 1967; Barclay, 1986), in which remembering is assumed to involve reconstructive inferences that may supplement the retrieval process. In terms of the framework presented here, however, it should not matter much whether a candidate answer is produced by a retrieval process such as ecphory or, instead, by some type of inferential, schema-based reconstruction process; much of the surrounding control processes would remain essentially the same. In any case, there has been very little work, if any, detailing the processes involved in reconstructive remembering.

The results of each retrieval (ecphory) attempt are evaluated by the rememberer to determine whether the sought-for information has been reached. If not, the search parameters may be refined, and a fresh retrieval attempt is made. Because of the critical role that search parameters play in retrieval, the metacognitive control exerted in the evaluation of results and in the consequent updating of these parameters has a high impact on remembering. The iterative search process is terminated either when the rememberer gives up (e.g., after drawing a blank or running out of time) or when a retrieved answer is identified as the best one that can be found.

Once a best-candidate answer has been reached, other factors now come into play in converting that answer into an overt memory response (Tulving, 1983). For example, the decision whether to report the best answer or withhold it and respond "don't know" (Koriat and Goldsmith, 1996b), and the decision regarding the level of generality or precision (grain size) at which to report the answer (Goldsmith et al., 2002), are both under the strategic control of the rememberer.

In what follows, our discussion of controlled processes in remembering will be divided in terms of the processes that take place before retrieval, those that take place after the retrieval of some candidate answer, and finally, the processes that take place in deciding what to report, and how.

## 2.18.3 Controlled Preretrieval Processes

### 2.18.3.1 Deciding Whether to Initiate or Forgo a Memory Search

When confronted with a memory query, one does not always proceed immediately to initiate retrieval. Rather, in many cases a preliminary feeling of knowing (FOK) may signal that it is not worthwhile to search for the answer, either because it is not in memory or because it might require more time and effort than is warranted under the circumstances. Thus, a preliminary monitoring stage may be postulated in which one makes a rough assessment regarding the availability of the answer in memory and the effort needed to access it. The initial FOK is assumed to rely on the overall familiarity of the query (Schwartz and Metcalfe, 1992; Nhouyvanisvong and Reder, 1998) and the extent to which it brings to mind some fragmentary clues (Koriat, 1993, 1995). Reder (1987) argued that a fast, preretrieval FOK is routinely and automatically made in response to the familiarity of the terms of a memory query. She found that the latency of making a fast FOK is shorter than that of accessing the answer, suggesting that preliminary FOK is not based on the retrieval of an answer. If the question does not produce a feeling of familiarity, chances are that one will not initiate a deliberate search for the answer. Glucksberg and McCloskey (1981; see also Kolers and Palef, 1976), for example, showed that people answer "I don't know" more rapidly when no potentially relevant information is accessible ("Does Margaret Thatcher use an electronic toothbrush?") than when some information can be retrieved ("Is Kiev in the Ukraine?"). They proposed that low preliminary FOK can cause people to forgo a memory search. Note, however, that a preliminary 'Don't Know' response appears not to prevent automatic activations that may ultimately evoke the solicited target (Koriat and Lieblich, 1977).

Using an episodic cued recall task, Malmberg (in press) has recently shown that enhanced cue familiarity increases the time participants search for the answer before giving up and also increases the likelihood of retrieving the correct answer. Familiarity, however, appeared to have little effect when participants were led to believe that familiarity was not correlated with the memorability of the target. Thus, it would seem that the effects of preliminary FOK on the initiation of a memory search are at least partly strategic. In fact, Reder and her associates argued that preliminary FOK can guide the choice of question-answering strategy, as discussed in the next section. Note also that cue familiarity may affect not only the initiation of the search for the target but also the continuation of the search after it has been initiated, as suggested, perhaps, by the results of Malmberg.

### 2.18.3.2 Choosing a Search Strategy

Several strategies of memory search have been discussed in the literature. The strategy used to search memory determines in part the context of retrieval, the generation of additional retrieval cues, and the ways those cues are used to retrieve information from memory. By controlling the choice of search strategy, either initially or after a previous strategy has failed, the rememberer can influence the course of remembering as well as its results.

One prominent strategy is embodied in the classic two-stage generate–recognize model (Bahrick, 1969, 1979). In this strategy, the rememberer uses the available cues to define a region in memory in which the solicited item is likely to reside (e.g., "vegetables," "words strongly related to *doctor*," "Spanish family names"). Candidate items are then generated, and a subsequent monitoring process is used to select (recognize) the target from among them. For example, when trying to recall the name of an old acquaintance, one might run through a number of female names in one's head and hope that one of the names will be recognized as the target. In response to theoretical and empirical challenges (e.g., Thomson and Tulving, 1970; Tulving and Thomson, 1973; Wiseman and Tulving, 1976), more recent versions of the generate–recognize model (Jacoby and Hollingshead, 1990; Weldon and Colston, 1995; Higham and Tam, 2005, 2006) acknowledge that generated candidates may be a joint product of semantic and episodic influences (*See* Chapter 2.27). Nevertheless, these models continue to embody a memory search strategy that might be portrayed as 'casting a wide net' rather than trying to retrieve the target item directly.

Metacognitive knowledge about subtle characteristics of the encoding and retrieval contexts can guide the controlled use of the generate–recognize strategy. For example, Higham and Tam (2005) found that participants were sensitive to the strength of the semantic cue–target relations in studied lists of paired associates, and that this awareness influenced the set of plausible candidates that were generated during a cued-recall test: When participants expected weak cue-to-target relations, they were not likely to generate targets strongly related to the retrieval cues. Koriat and Lieblich (1974) also observed that participants' guesses of a target word while in a tip-of-the-tongue (TOT) state are sensitive to the specific definition of the population from which the target is said to have been drawn.

Clearly, however, rememberers do not always resort to a generate–recognize strategy. As Bahrick (1979) has observed, one does not recall the name of his wife by generating a series of female names and selecting the correct name. Instead, in this case and many others, a direct-retrieval process is invoked, in which relatively specific and constrained retrieval cues allow one to 'home in' directly on the target representation in memory. This process is assumed to be automatic and effortless. In fact, Bahrick (1979) suggested that only when direct retrieval fails do people resort to other strategies. Guynn and McDaniel (1999) proposed that, when a large amount of contextual information has been encoded along with the target, rememberers prefer direct retrieval over the generate–recognize strategy because the contextual information facilitates a narrowly focused ecphory operation. Higham and Tam (2005) suggested that direct-retrieval and generate–recognize strategies can be conceived as lying along a continuum representing the degree to which retrieval is constrained.

Jacoby and colleagues proposed a controlled mode of retrieval that they call source-constrained retrieval – the deliberate use of target-source information to constrain what comes to mind during retrieval. In a series of experiments (Jacoby et al., 1999, 2005a,b), participants studied a list of words under shallow or deep encoding and were tested using an old/new recognition test. When they were later tested for their memory of the foils that appeared on the first test, their performance was better for the foils that had appeared on a test of deeply encoded study items than for those that had appeared on a test of shallowly encoded study items. This result was taken to suggest that the participants had used their metacognitive knowledge of the original encoding operations to constrain their retrieval on the first test by applying these same operations to the test probes. The same pattern was not found for elderly participants, presumably because elderly people fail to take advantage of their knowledge about encoding operations to constrain their retrieval.

The next strategic choice to be considered involves basing one's answer on reconstructive inference rather than on the reproductive retrieval of stored information (Neisser, 1984; Hall, 1990). Several researchers have proposed that the choice between reconstructive and reproductive remembering is, at least partly, under the control of the rememberer (Reder, 1987; Ross, 1989). Reder (1987) showed that, when the familiarity of the question is low, people tend to answer the question by making plausible inferences about the answer on the basis of a variety of cues, rather than by attempting to retrieve the answer directly from memory. She also suggested that the tendency to rely on plausible inference increases in old age (Reder et al., 1986). Similarly, Ross (1989) proposed that, when accuracy motivation is low, people tend to utilize a schema-based reconstruction strategy rather than engaging in an effortful reproductive retrieval. For example, in attempting to recall one's past attitudes, a person might use his or her present attitudes as a benchmark against which to reconstruct the past attitudes in light of an implicit theory of stability or change. To reconstruct how one felt 5 years ago, one might ask oneself: Is there any reason to believe that I felt differently then than I do now (Ross, 1989)? Several studies have shown that people tend to exaggerate the similarity between their present and past attitudes (e.g., Bem and McConnell, 1970).

Finally, a fourth general strategy can be identified that might be called 'mediated' retrieval, in which one initially sets out to retrieve contextual information that may then assist in generating further cues to guide more direct retrieval attempts (e.g., Williams and Hollan, 1981; Reiser et al., 1985). For example, when trying to remember the gifts one received at one's last birthday party, a person might first try to retrieve the general party context, including the friends who attended, in order to make the subsequent retrieval of the gifts themselves more efficient.

#### 2.18.3.3 Specifying the Initial Context of Search and Generating Internal Retrieval Cues

As discussed earlier, retrieval cues play a critical role in the efficient retrieval of information from memory. That role begins with the cues that are presented explicitly in the memory query and those that are available implicitly in the more general retrieval context. Such cues may aid retrieval either automatically or in a more deliberate and controlled manner. The controlled exploitation of cues is particularly transparent when retrieval is difficult and prolonged.

One searches one's memory in a controlled manner by specifying certain characteristics of the solicited information as retrieval cues. Norman and Bobrow (1979) termed such specifications 'descriptions.' Descriptions may include the context of the solicited event (e.g., time, place) and additional information. Norman and Bobrow suggested that the descriptions are continually updated after each retrieval attempt. Following up on these ideas, Burgess and Shallice (1996) proposed a controlled descriptor process that is responsible for translating memory queries into a form that corresponds to the way the relevant information is stored in long-term memory. They suggested that one of the causes of clinical confabulation disorder is impaired descriptor processes.

Other researchers have put forward similar ideas. Norman and Schacter (1996; Schacter et al., 1998), for example, used the term 'focusing' to describe the preliminary stage in retrieval in which the rememberer refines the description of the characteristics of the sought-for episode. Similarly, Moscovitch and Melo (1997) suggested that confabulators might be impaired in the strategic use of general and personal knowledge to constrain their memory search so as to home in on the target. Dab and colleagues (Dab et al., 1999) described a patient whose confabulations apparently stem from deficient cue setting. In contrast to other confabulators, this patient had preserved memory and postecphoric verification abilities but exhibited a selective impairment of the search descriptor process. Finally, the work of Jacoby and colleagues on source-constrained retrieval, mentioned earlier (Jacoby et al., 2005a,b), suggests that rememberers use contextual knowledge to constrain their retrieval queries, and that elderly people may be particularly deficient in this type of retrieval control.

Once an initial search description has been formed, further cues may be recruited during the search. Indeed, several studies have identified a reiterative pattern that occurs in the course of arduous remembering. Williams and Hollan (1981), for example, proposed that remembering consists of a series of kernel retrieval processes, each including three stages: a memory region is specified in which a search is to be conducted, that region is searched for additional clues, and the information retrieved is evaluated. Information that passes the evaluation is then used to guide the next retrieval attempt. This cycle is repeated, gradually refining the description of the information to be searched, until the search closes in on the target. Thus, in attempting to retrieve the names of high school classmates, participants in Williams and Hollan's (1981) study produced an enormous amount of information that was incidental to the task of recalling the names, including details about the school, about where people lived, and so forth. Examination of this information suggested that its main function was to probe one's memory for additional clues that could better specify a new context for search.

Similarly, Reiser and his associates (Reiser et al., 1985, 1986), in studying the recall of autobiographical episodes, also emphasized that one memory retrieval can be undertaken in order to provide cues for a subsequent retrieval. According to their context-plus-index model, specific personal episodes are recalled by first recovering the general context in which they were likely to have been encoded and then specifying the features that uniquely distinguish these experiences from others in that context. They proposed that scripts (e.g., 'eating in restaurants'; Schank, 1982) typically serve as convenient retrieval contexts. Burgess and Shallice (1996) also noted that participants did not always retrieve the target memory record directly but sometimes recovered a useful cue first. For example, it was not uncommon for participants to answer the question "What was the weather like yesterday morning?" by trying to remember first what they were wearing.

Similar processes appear to take place in retrieving information from semantic memory. A study by Walker and Kintsch (1985) suggests that retrieving the members of natural categories also relies on the recovery of context. Verbal protocols suggested a series of two-stage cycles: generating a context in which category members are likely to be found, and then using that context as a retrieval cue to produce the category members themselves. Interestingly, most of the contexts generated were episodic rather than abstract-semantic (e.g., in searching for automobiles, one might visualize the cars in a parking lot or in front of one's dormitory).

We noted earlier that retrieval is more efficient when the retrieval context closely matches the encoding context. Rememberers can take advantage of this principle by deliberately attempting to reinstate the encoding context. Thus, for example, a study by Smith (1979) suggests that mental reinstatement of the learning environment may be almost as beneficial for retrieval as actual, physical reinstatement. Notably, mental context reinstatement has been incorporated into the Cognitive Interview (Fisher and Geiselman, 1992) as a means of facilitating witness recollection; prior to answering specific questions about a past event, witnesses are instructed to mentally recreate the context or state that existed at the time of the original event. Another memory principle that can be taken advantage of in a controlled manner is the effect of schema activation on retrieval. For example, in Anderson and Pichert's (1978) classic experiment, participants read a story about two boys playing in a house from one of two perspectives, that of a home buyer or that of a burglar. After a standard recall task, participants were asked to recall the story again, now adopting the other perspective. The participants could now recall additional details that were related to the new perspective.

So far we have emphasized the deliberate use of retrieval cues in remembering. However, throughout the search, automatic activations can bring to mind a variety of associations and memories. Thus, retrieval often involves a complex interplay between a controlled process and the automatic involuntary emergence of ideas and associations (Collins and Loftus, 1975; Nelson et al., 1998) that emanate from the retrieval context or from the information already recovered (Moscovitch, 1989; Jacoby, 1991). Sometimes the controlled process will seize onto ideas that emerged involuntarily and use them as intermediate cues on the way to the sought-for target. In other cases they may be recognized as unwanted 'interlopers,' and effort will be exerted to oppose their interfering influence (section 2.18.5.3; Jones, 1989).

## 2.18.4 Retrieval (Ecphory)

As explained in section 2.18.3.2, in this chapter the retrieval-ecphory operation is treated as an automatic, ballistic process whose course is not under the control of the rememberer. Understanding the nature of this process has been one of the longstanding goals of memory research, and many formal models have been proposed to describe it (e.g., Raaijmakers and Shiffrin, 1980, 1981; Hintzman, 1987; Murdock, 1993). We assume that rememberers can exert control over retrieval only by affecting the input to the retrieval operation. Such control, as the preceding discussion suggests, can have a very large impact on the outcome of the retrieval operation in particular, and on the search process generally. In addition, rememberers also make use of the retrieval output to guide subsequent retrieval operations and to convert the retrieved information into an overt response. These aspects of postretrieval control are covered in the following sections.

## 2.18.5 Controlled Postretrieval Processes

As noted earlier, search and retrieval can be conceptualized as a reiterative process in which a description is formed, cues are recruited to facilitate the search, candidate answers are evaluated, and – depending on the results – the search may be terminated or the cycle may continue. In this section we focus on processes that take place following the retrieval of candidate answers. These include monitoring and control processes that aid in achieving one's goals. First, rememberers monitor whether the search is on the right track and, if necessary, refine and reformulate the memory description or change the retrieval strategy. Second, they evaluate the correctness of retrieved candidate answers in deciding whether or not the target has been reached. Third, inhibition may be applied to reduce the interference from items of information that come to mind but are judged to be incorrect. Finally, in deciding whether to continue or terminate the search, rememberers may assess the likelihood of success and the additional time and effort needed to reach the target. Such an assessment may be particularly important when remembering is done under pressure, for example, when a lecturer quickly decides to settle for 'several researchers have shown' instead of continuing to search for the specific names of the researchers. We examine each of these processes in turn.

### 2.18.5.1 Updating and Refining the Search Strategy and Internal Retrieval Cues

In the previous section we emphasized the control exerted by rememberers in setting up the initial search parameters (internal retrieval cues and overall search strategy). We also noted, and reemphasize here, the reiterative-cyclical nature of the search process. After each retrieval attempt, these search parameters may be refined and reformulated in light of the information that has been retrieved. As observed by Norman and Bobrow (1979) and by several researchers subsequently, the 'descriptions' of the sought-for information are continuously updated during the retrieval cycle, based on newly retrieved information.

Search strategies may also be changed in light of the retrieved information. For example, participants may abandon one strategy in response to the retrieval of information that appears to be particularly useful in the context of a different strategy (Williams and Santos-Williams, 1980). When a controlled, deliberate search proves unsuccessful, however, rememberers may decide to relinquish strategic control altogether, adopting a passive-receptive attitude. Nickerson (1981) noted that, in retrieving words from lists, participants often begin with a passive attitude and then switch to an active, systematic search when the passive approach no longer yields a satisfactory return (see also Walker and Kintsch, 1985). Koriat and Melkman (1987) observed a similar pattern and also showed that, when attentional resources are diverted, the retrieval of words from a list becomes less controlled, moving along associative links between the words rather than along conceptual-logical relations.

### 2.18.5.2 Evaluating the Correctness of Retrieved Information

A great deal of work emphasizes the importance of postretrieval monitoring processes that evaluate the relevance and correctness of retrieved information (e.g., Burgess and Shallice, 1996; Kelley and Jacoby, 1996; Schacter et al., 1998; Koriat, 2000; Mitchell and Johnson, 2000). On the basis of these processes, one decides not only whether each piece of information that comes to mind is correct or not but also whether the search is on the right track, whether to continue searching for additional candidate responses, and which of the many candidates that came to mind is the best candidate answer. In a later section we discuss the further crucial role of monitoring processes in deciding whether or not to report the best candidate answer, and in what form. The operation of these processes is particularly important in real-life situations (e.g., eyewitness testimony) in which a premium is placed on accurate reporting.

Discussions of metacognition generally distinguish between two basic types of monitoring processes (Koriat and Levy-Sadot, 1999). Information-based processes involve analytic, deliberate inferences in which beliefs and knowledge in long-term memory are consulted and weighed to reach an educated judgment. Experience-based processes, in contrast, are sensitive to online mnemonic cues, such as retrieval fluency, that derive from the experience of remembering itself. These cues give rise to subjective feelings (e.g., a sense of conviction), which then serve as the bases for metacognitive judgments (Strack, 1992; Kelley and Jacoby, 1996; Koriat and Levy-Sadot, 1999).

As an example of information-based, analytic monitoring, rememberers may base their confidence in the correctness of a particular candidate response on the weight of the evidence that they can marshal in favor of that candidate relative to the evidence in support of the alternative candidates (e.g., Koriat et al., 1980; Griffin and Tversky, 1992; McKenzie, 1997; Yates et al., 2002). Rememberers may also base their confidence on metacognitive beliefs about their own competence and skills (Dunning et al., 2003; Perfect, 2004) and about the way in which various factors can affect memory performance (Dunlosky and Nelson, 1994; Mazzoni and Kirsch, 2002).

In contrast to this type of analytic and deliberate evaluation, experience-based monitoring relies on mnemonic cues that derive from the online processes of remembering. Such cues as the ease with which information comes to mind, or its vividness, may contribute implicitly to the subjective confidence in the correctness of that information. For example, it has been observed that the more effort and the longer the deliberation needed to reach an answer, the lower is the confidence in that answer (e.g., Nelson and Narens, 1990; Robinson et al., 1997; Koriat et al., 2006). Kelley and Lindsay (1993) showed that when priming speeds up the emergence of an answer, confidence judgments also increase accordingly. This effect occurred even for plausible but incorrect answers. Although typically correct answers are associated with shorter latencies than incorrect answers, so that response latency is diagnostic of the correctness of the answer that is retrieved or recognized, there are situations in which retrieval fluency can be misleading (Chandler, 1994). For example, asking participants to imagine some childhood events increased confidence that these events did indeed happen in the past (Garry et al., 1996). Merely being asked about an event twice also increased subjective confidence. Possibly, imagining an event or attempting to recall it increases its retrieval fluency, which in turn contributes to the confidence that the event has occurred.

A prominent theory that includes both automatic and controlled monitoring processes is Johnson's (1997) source monitoring framework. According to this framework, in discriminating the origin or source of information, people take advantage of the fact that mental experiences from different sources (e.g., perception vs. imagination) differ on average in their phenomenal qualities such as visual clarity and contextual details (*See* Chapter 2.19). Although these diagnostic qualities can support a rapid, heuristically based source monitoring, sometimes more strategic, deliberative processes may be applied. Both types of processes require setting criteria for making a judgment and procedures for comparing activated information to the criteria. Closely related processes have been discussed in the context of Jacoby and Kelley's attributional approach to memory (e.g., Jacoby et al., 1989; Kelley and Rhodes, 2002) and in Whittlesea's SCAPE framework (e.g., Whittlesea and Williams, 2001a,b; Whittlesea, 2002).

Many memory errors are the result of source confusions – the attribution of retrieved elements to the wrong context (Johnson, 1997). For example, the effects of misleading postevent information have been attributed, at least in part, to deficient source monitoring, by which the postevent misinformation is wrongly attributed to the witnessed event (see Lindsay, 1994; Mitchell and Johnson, 2000). Source confusions can arise when the activated information during retrieval is incomplete or ambiguous, or when the cues used in attributing information to sources are not diagnostic. Divided attention during encoding has been found to impair source monitoring (Craik and Byrd, 1982), presumably because they disrupt contextual binding. High perceptual similarity between two sources, as well as similarity in the encoding processes, also increase source confusions (Ferguson et al., 1992; Dodson and Johnson, 1996). Although vividness and perceptual detail are generally diagnostic of actual memories (Conway et al., 1996), thinking about imagined events also increases their vividness, thereby impairing reality monitoring for these events (Suengas and Johnson, 1988).

Several mechanisms have been proposed that can help reduce source confusions and reject false memories (see Odegard and Lampinen, 2006). For example, distinctive encoding manipulations have been shown to reduce the occurrence of false recall and recognition. Such manipulations include presenting each word together with a picture representing it (Israel and Schacter, 1997; Schacter et al., 1999), visual rather than auditory presentation (Smith and Hunt, 1998), having participants say the words out loud at study (Dodson and Schacter, 2001), or having the participants rate the pleasantness of the words during study (Smith and Hunt, 1998). Schacter et al. (1999) have explained such findings in terms of a *distinctiveness heuristic,* a mode of responding based on participants' metacognitive belief that true memory of studied items should include recollection of distinctive details. Participants can use this heuristic to reject foils that evoke memorial experiences lacking the distinctive qualities known to be present at study. A similar metacognitive strategy has been suggested by Strack and Bless (1994) to underlie judgments of nonoccurrence. They showed that, if an event is judged to be memorable (salient) but elicits no clear recollection during testing, it can be rejected with high confidence as not having occurred. In contrast, in the absence of a clear recollection of a nonmemorable event, rememberers may infer that the event actually had occurred but had simply been forgotten. Also, studying material under conditions unfavorable for learning (or expecting fast forgetting, Ghetti, 2003) results in a relatively high rate of false alarms for nonmemorable distractors.

In the framework of Fuzzy Trace Theory, Brainerd et al. (2003) proposed recollection rejection as another mechanism for identifying and editing out false memories. By this mechanism, a distractor that is consistent with the gist of a presented item may be rejected when the verbatim trace of that item is recollected. Thus, participants can reject 'SOFA' as having occurred in the study list if they recall that the word 'COUCH' was in the list and if they have noticed that all words in the study list were unrelated to each other. Recollection rejection has been shown to operate in rejecting false narrative statements (Brainerd et al., 2006) and may also occur for self-generated candidate responses that emerge during recall.

Finally, Burgess and Shallice's (1996) model, mentioned earlier, also includes a mechanism for the screening of retrieved information. The model assumes that 'editor' processes are initiated whenever a descriptor is set. These processes check that retrieved memory items do not contradict previously retrieved elements of the event, and that they are compatible with the overall descriptor requirements. Evidence for the operation of such a mechanism comes from error corrections in verbal protocols obtained during autobiographical recollections of recent everyday events. One participant, who was asked to describe the first thing that came to mind that happened to him in January, was recorded thinking:

> Something that happened in January? . . . I completed a major sale. No! I didn't complete a major sale in January at all. I didn't sell anything at all in January because I remember looking at the board and that was blank." (Burgess and Shallice, 1996: 382)

Applying their model to the study of confabulations, Burgess and Shallice (1996) pointed to impaired editor processes, along with insufficiently focused retrieval descriptions, as two of their main causes.

### 2.18.5.3 Inhibiting Wrong/Irrelevant Information

As noted earlier, a great deal of unwanted information is retrieved during the search for a solicited target, which must be cast aside as the search continues. Therefore, a potentially important contributor to successful retrieval is the efficient inhibition of such incidental information and, in particular, the inhibition of rejected candidate answers that would otherwise keep coming to mind and interfering with the search. The effect of such interference has been emphasized in studies of the TOT phenomenon, in which the failure to retrieve the correct target while in the TOT state is attributed, in part, to the interfering effect of 'interlopers' – plausible but wrong candidate answers that share some features with the target (Reason and Lucas, 1984; Jones, 1989; Burke et al., 1991).

It has been observed that retrieving some items of a studied list with the aid of category cues impairs the later recall of other studied items from the same category, but not of other unrelated studied items (Anderson et al., 1994; Anderson and Spellman, 1995; Anderson, 2003). This retrieval-induced forgetting has been attributed to inhibitory mechanisms that operate to suppress unwanted information in order to overcome retrieval competition (Anderson et al., 2000; Levy and Anderson, 2002). Hasher and her colleagues (Hamm and Hasher, 1992; Hasher et al., 1999) suggested that inhibitory processes are used to suppress goal-irrelevant information that has been activated in working memory, or to prevent candidate answers from being immediately reported, so that other candidates can also be retrieved and considered (Hasher and Zacks, 1988; Hasher et al., 1999; Radvansky et al., 2005). May and Hasher (1998) demonstrated that the controlled inhibition of the irrelevant contents of working memory is deficient in older adults, and in young adults during their off-peak time of the day.

*Directed forgetting* is another example of controlled inhibition in memory. Research indicates that, when people are instructed to forget a previously learned piece of information, they are often successful in reducing or eliminating the interference between that information and the subsequent retrieval of to-be-remembered information (Bjork and Woodward, 1973; Bjork, 1989). The underlying mechanism seems to involve inhibiting the retrieval of the to-be-forgotten information. Indeed, when memory is tested through recognition or relearning, or when it is tested through indirect measures of memory such as priming, performance on the to-be-forgotten items is typically comparable to that of to-be-remembered items (Basden et al., 1993; Bjork and Bjork, 1996).

#### 2.18.5.4 Deciding Whether to Continue or Terminate the Search

We have characterized the search process as reiterative, but it is, of course, not endless. At some point, the memory search must terminate – either when no relevant information can be retrieved or after some information (correct or incorrect) has been retrieved, and the rememberer either believes that the target has been reached or has given up. The decision to stop the search is at least partially under the control of the rememberer and is based on such factors as level of confidence in the best candidate answer produced so far, the feeling that one knows the answer even though it has not (yet) been retrieved, the amount of time and effort invested so far, and the incentives for successful performance.

Whereas it is self evident that high confidence in a retrieved answer will induce the rememberer to terminate the memory search, there is also evidence that this decision is affected by the feeling of knowing (FOK) regarding answers that have not yet been retrieved. When FOK is high, participants spend more time searching for the target before giving up than when FOK is low (Nelson and Narens, 1990; Barnes et al., 1999).

The decision to continue the search is also affected by the expected reward for correct retrieval. Loftus and Wickens (1970) found that the larger the reward offered at the time of retrieval, the more time participants spent before terminating the retrieval, although this did not affect their performance. More direct evidence comes from Barnes et al. (1999) in examining the ‘willingness to continue searching’ component of their metacognitive retrieval model. They assumed that the willingness to continue searching depends on two conflicting incentives – the reward for finding the correct answer and the cost of spending additional search time. For example, in most exam situations, continuing to search for an answer to one question is beneficial to the extent that this allows the correct answer to be reached, but it is detrimental to the extent that this takes away from the time that can be spent on other questions. Manipulating the reward for each correct answer and the cost of additional search time on a cued-recall test, Barnes et al. (1999) found that both higher rewards and lower costs induced the participants to take longer before responding. This increased the number of correct responses and decreased the number of omission errors without increasing the number of commission errors – indicating that the additional retrieval effort was not in vain.

### 2.18.6 Controlled Report Processes

#### 2.18.6.1 Deciding Whether or Not to Report an Answer

Much memory research has used forced-report testing procedures, such as forced-choice recognition or forced cued recall, in which the participant is required to select/provide an answer to each and every test probe. In most everyday memory situations, however, as in many laboratory recall tasks, rememberers have the option of *free report;* that is, they are allowed to decide for themselves whether to answer a particular memory query, or instead to respond 'don't know' (or refrain from responding).

The option of free report is particularly crucial in situations, such as courtroom testimony, in which a premium is placed on accurate reporting. Koriat and Goldsmith (1994, 1996b) showed that, when participants are given the option of free report and a moderate incentive for accurate reporting (a penalty for each wrong answer equal to the reward for each correct answer), they are able to boost the accuracy of what they report substantially in comparison to forced-report testing. They do so by withholding best-candidate answers that are likely to be wrong. For example, in one study (Koriat and Goldsmith, 1994, Experiment 1), the option of free report allowed participants to increase their recall accuracy from 47.6% in forced report to 76.6%. Moreover, when given an even stronger accuracy incentive (a 10:1 penalty-to-reward ratio; Koriat and Goldsmith [1996b, Experiment 1], or the loss of all winnings if a single wrong answer is volunteered, Koriat and Goldsmith [1994, Experiment 3]), report accuracy was boosted even further. In each case, however, the increased report accuracy came at the price of a reduction in the quantity of correct information reported – that is, a quantity-accuracy trade-off (see also Barnes et al., 1999; Kelley and Sahakyan, 2003).

The existence of a quantity-accuracy trade-off means that rememberers must strive to find a compromise between these two conflicting aims in regulating their reporting. Consider, for example, a courtroom witness who has sworn "to tell the whole truth and nothing but the truth." Generally, it is not possible to fulfill both endeavors simultaneously. How, then, should the witness proceed?

Koriat and Goldsmith (1996a) proposed a model (for similar models, see Barnes et al., 1999; Higham, 2002), in which one first assesses the likelihood that one's best candidate answer is correct and then compares this assessment to a report criterion. The answer is volunteered if its assessed probability of being correct passes the criterion; otherwise, it is withheld. The setting of the criterion is assumed to depend on the relative incentives for accuracy and quantity; in general, report accuracy should increase, but the quantity of correct answers should decrease as the criterion level is raised.

In line with this model, a very strong relationship was found between the tendency to report an answer under free-report conditions and subjective confidence in the answer (assessed probability that the answer is correct). In one study, for example, the mean within-participant gamma correlation between confidence in the answer and the decision to volunteer it or withhold it on a recall test was .95 (Koriat and Goldsmith, 1996b, Experiment 1; see also Kelley and Sahakyan, 2003). In addition, manipulating the incentives for accurate reporting in the manner described earlier (by manipulating the relative rewards and penalties for correct and incorrect answers, respectively) induced rememberers to adjust their report criterion accordingly; higher levels of confidence were required for reporting answers under a strong accuracy incentive than under a more moderate accuracy incentive (Koriat and Goldsmith, 1996b, Experiment 1; Kelley and Sahakyan, 2003, Experiment 1). Finally, modeling the report decision in terms of a confidence criterion (cutoff), with the level of the criterion for each participant allowed to vary as a free parameter, yielded a very good fit with the data, accounting for about 94% of the participants' actual report decisions under recall testing (Koriat and Goldsmith, 1996b, Experiment 1). Similar levels of fit were found by Kelley and Sahakyan (2003).

The consideration of the role of metacognitive monitoring and control processes in reporting has yielded some interesting insights concerning variables that affect memory accuracy and quantity performance. One, of course, is the effect of accuracy motivation mentioned earlier. A second important variable is monitoring effectiveness, that is, the extent to which the rememberer can distinguish between correct and incorrect answers. On the one hand, as monitoring effectiveness increases, the option of free report allows one to screen out wrong candidate answers without also mistakenly screening out correct candidate answers, thereby reducing the rate of the quantity-accuracy tradeoff. On the other hand, when monitoring effectiveness is impaired, the exercise of the option to withhold answers may yield little or no benefit in terms of report accuracy (Koriat and Goldsmith, 1996b; Rhodes and Kelley, 2005; Kelley and Sahakyan, 2003) and may simply reduce the quantity of correct information that is reported (Higham, 2002), compared with forced report.

A third important variable is test format with – recall versus recognition. This variable has been implicated in both traditional, quantity-oriented research and in more naturalistic, accuracy-oriented research, with opposing implications. Whereas the general finding from decades of laboratory research (e.g., Brown, 1976) is that recognition testing is superior to recall testing in eliciting a greater quantity of correct information from memory, the established wisdom in eyewitness research, for example, is that recall is superior to recognition in eliciting accurate information from rememberers (e.g., Hilgard and Loftus, 1979; Neisser, 1988). Koriat and Goldsmith (1994), however, showed that this recall–recognition paradox actually stems from the common confounding between test format (recall vs. recognition) and report option (free vs. forced). Typically, recognition participants are forced either to choose between several alternatives or to make a yes–no decision regarding each and every item, whereas recall participants have the freedom to withhold information that they are unsure about. Comparing performance on a free-recognition test (in which participants had the option to respond 'don't know' to individual items), to a free-recall test, Koriat and Goldsmith (1994) found that recognition quantity performance was still superior to recall, but now recognition accuracy was as high or even higher than recall accuracy. An examination of the underlying memory and metamemory components of recall and recognition performance (*See* Chapter 2.20; Koriat and Goldsmith, 1996b) indicated that monitoring effectiveness was in fact somewhat lower for recognition than for recall testing, but that this disadvantage was more than compensated for by superior memory access and the adoption of a more conservative report criterion under recognition testing.

The consideration of the role of metacognitive monitoring and control processes in reporting has also yielded interesting insights with regard to other important topics and questions, such as developmental changes in memory accuracy (Koriat et al., 2001; Roebers et al., 2001), memory decline in the elderly (Jacoby, 1999; Pansky et al., 2002; Kelley and Sahakyan, 2003; Rhodes and Kelley, 2005), cognitive and metacognitive impairment in schizophrenia (Danion et al., 2001; Koren et al., 2006), psychometric and scholastic testing (Koriat and Goldsmith, 1998; Higham, 2007), and the classic encoding specificity principle (Higham, 2002; Higham and Tam, 2005). As just one example, there has been a question about the reliability of children's memory, particularly in the area of legal testimony, (e.g., Bruck and Ceci, 1999). Yet, Koriat et al. (2001) showed that children as young as 8 or 9 years old can regulate their memory reporting to produce a more accurate record of past events when they are allowed to screen out wrong answers and when they are explicitly motivated to do so. Furthermore, like adults, they are also sensitive to specific levels of accuracy incentive, increasing the accuracy of their reports further when a higher premium is placed on memory accuracy. However, the children in that study (see also Roebers et al., 2001) and elderly adults in other studies (Pansky et al., 2002; Kelley and Sahakyan, 2003; Rhodes and Kelley, 2005) were found to be less effective than young adults in utilizing the option to withhold answers to enhance their accuracy.

Of course, there may be variables whose influences are not amenable to control by way of report regulation. For example, Payne et al. (2004) observed that when participants were allowed the option of free report, they could enhance their overall memory accuracy, but the withholding of answers did not reduce stereotype bias. Their findings suggest that stereotypes distort memory through an unconscious-accessibility bias to which subjective confidence is insensitive. The implication is that any variable that affects memory performance without affecting subjective confidence (i.e., that cannot be monitored) will not be susceptible to report control.

#### 2.18.6.2 Deciding on the Grain Size of the Reported Answer

In addition to the exercise of report option, another means by which rememberers regulate the accuracy and amount of information that they report is controlling the *grain size* of their report, that is, the precision or coarseness of their answers (Yaniv and Foster, 1995, 1997; Goldsmith and Koriat, 1999; Goldsmith et al., 2002, 2005). For example, when asked to specify what time an event occurred, a rememberer who is unsure might provide a relatively coarse response such as "in the late afternoon" or "between 5.00 and 6.00 p.m.," rather than venture a more precise response. In fact, Neisser (1988) observed that, when answering open-ended questions, participants tended to provide answers at a level of generality at which they were "not likely to be mistaken." Of course, more coarsely grained answers, while more likely to be correct, are also less informative. Thus, Goldsmith et al. (2002) proposed that the control of grain size is guided by an accuracy-informativeness trade-off (see also Yaniv and Foster, 1997), similar to the accuracy-quantity trade-off that guides the exercise of report option. They found that, when participants were allowed to control the grain size of their report, they did so in a strategic manner, sacrificing informativeness (precision) for the sake of accuracy when their subjective confidence in the more precise-informative answer was low. The participants also took into account the relative payoffs for accuracy and informativeness in choosing the grain size of their answers; they tended to provide more precise answers (thus taking a greater risk of being wrong) when the relative payoff for informativeness was high than when it was low. The monitoring and control processes involved in the regulation of memory grain size appear to be similar to those underlying the decision to volunteer or withhold specific items of information, implying perhaps the use of common metacognitive mechanisms.

As in the case of report option, a consideration of the control of grain size in memory reporting has begun to shed light on other memory phenomena and issues. One example is the potential role of control over grain size in modulating the changes that occur in memory over time. Goldsmith et al. (2005) examined the regulation of report grain size over different retention intervals. Starting with the well-known finding that people often remember the gist of an event though they have forgotten its details, they asked whether rememberers might exploit the differential forgetting rates of coarse and precise information in regulating the accuracy of the information that they report over time. The results suggested that, when given control over the grain size of their answers, people attempt to maintain a stable level of report accuracy by providing coarser answers at longer retention intervals.

In this section we focused on the control of grain size that takes place at the reporting stage. There is evidence, however, that rememberers can also control the level of coarseness or precision at which they retrieve information (Anderson et al., 2001; Brainerd et al., 2002; Koutstaal, 2003; Koutstaal and Cavendish, 2006). Koutstaal (2003), for example, showed that rememberers can flexibly alternate between attempts to query memory at a highly specific level and attempts to query memory at a categorical level, and that this flexibility is somewhat impaired in older participants. Moreover, Koutstaal and Cavendish (2006) found that initially inducing participants to adopt and use a gist-based retrieval orientation can impair performance on a subsequent memory task that requires a more precise retrieval orientation.

## 2.18.7 Concluding Remarks

In this chapter, we examined the processes of voluntary remembering that are under the control of the rememberer. Such control is evident throughout the course of remembering, from the initial decision regarding whether and how to begin the memory search, until the final decision regarding how the retrieved information is to be reported. The investigation of self-controlled processes in remembering presents a methodological challenge to students of memory, because such processes are, by definition, less amenable to strict experimental control. Yet, as evidenced by the work reviewed in this chapter, recent years have seen a growing willingness to face this challenge. Clearly, however, much more work needs to be done to illuminate the underlying mechanisms of controlled remembering and clarify the intricate interplay between controlled and automatic memory processes. Ultimately, research should be targeted toward integrating these processes into more general theories of memory and remembering.

## References


Anderson JR, Budiu R, and Reder LM (2001) A theory of sentence memory as part of a general theory of memory. *J. Mem. Lang.* 45: 337–367.

Anderson MC (2003) Rethinking interference theory: Executive control and the mechanisms of forgetting. *J. Mem. Lang.* 49: 415–445.

Anderson MC, Bjork EL, and Bjork RA (2000) Retrieval-induced forgetting: Evidence for a recall-specific mechanism. *Psychon. Bull. Rev.* 7: 522–530.

Anderson MC, Bjork RA, and Bjork EL (1994) Remembering can cause forgetting: Retrieval dynamics in long-term memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 1063–1087.

Anderson MC and Spellman BA (1995) On the status of inhibitory mechanisms in cognition: Memory retrieval as a model case. *Psychol. Rev.* 102: 68–100.

Anderson RC and Pichert JW (1978) Recall of previously unrecallable information following a shift in perspective. *J. Verbal Learn. Verbal Behav.* 17: 1–12.

Bahrick HP (1969) Measurement of memory by prompted recall. *J. Exp. Psychol.* 79: 213–219.

Bahrick HP (1979) Broader methods and narrower theories for memory research: Comments on the papers by Eysenck and Cermak. In: Cremak LS and Craik FIM (eds.) *Levels of Processing in Human Memory*, pp. 141–156. New Jersey: Erlbaum.

Barclay CR (1986) Schematization of autobiographical memory. In: Rubin DC (ed.) *Autobiographical Memory*, pp. 82–99. New York: Cambridge University Press.

Barnes AE, Nelson TO, Dunlosky J, Mazzoni G, and Narens L (1999) An integrative system of metamemory components involved in retrieval. In: Gopher D and Koriat A (eds.) *Attention and Performance XVII: Cognitive Regulation of Performance: Interaction of Theory and Application*, pp. 287–313. Cambridge MA: MIT Press.

Bartlett FC (1932) *Remembering: A Study in Experimental and Social Psychology*. New York: Cambridge University Press.
Basden BH, Basden DR, and Gargano GJ (1993) Directed forgetting in implicit and explicit memory tests: A comparison of methods. *J. Exp. Psychol. Learn. Mem. Cogn.* 19: 603–616.
Bem DJ and McConnell HK (1970) Testing the self-perception explanation of dissonance phenomena: On the salience of premanipulation attitudes. *J. Pers. Soc. Psychol.* 14: 23–31.
Berntsen D (1996) Involuntary autobiographical memories. *Appl. Cogn. Psychol.* 10: 435–454.
Berntsen D (1998) Voluntary and involuntary access to autobiographical memory. *Memory* 6: 113–141.
Bjork RA (1989) Retrieval inhibition as an adaptive mechanism in human memory. In: Roediger HL, III, and Craik FIM (eds.) *Varieties of Memory and Consciousness: Essays in Honour of Endel Tulving*, pp. 309–330. Hillsdale, New Jersey: Erlbaum.
Bjork EL and Bjork RA (1996) Continuing influences of to-be-forgotten information. *Conscious. Cogn.* 5: 176–196.
Bjork RA and Woodward AE (1973) Directed forgetting of individual words in free recall. *J. Exper. Psychol.* 99: 22–27.
Brainerd CJ, Reyna VF, and Estrada S (2006) Recollection rejection of false narrative statements. *Memory* 14: 672–691.
Brainerd CJ, Reyna VF, Wright R, and Mojardin AH (2003) Recollection rejection: False-memory editing in children and adults. *Psychol. Rev.* 110: 762–784.
Brainerd CJ, Wright R, Reyna VF, and Payne DG (2002) Dual-retrieval processes in free and associative recall. *J. Mem. Lang.* 46: 120–152.
Brown J (*ed*.) (1976) *Recall and Recognition*. Oxford, UK: Wiley.
Bruck M and Ceci SJ (1999) The suggestibility of children's memory. *Annu. Rev. Psychol.* 50: 419–439.
Burgess PW and Shallice T (1996) Confabulation and the control of recollection. *Memory* 4: 359–411.
Burke DM, MacKay DG, Worthley JS, and Wade E (1991) On the tip of the tongue: What causes word finding failures in young and older adults? *J. Mem. Lang.* 30: 542–579.
Chandler CC (1994) Studying related pictures can reduce accuracy, but increase confidence, in a modified recognition test. *Mem. Cogn.* 22: 273–280.
Collins AM and Loftus EF (1975) A spreading-activation theory of semantic processing. *Psychol. Rev.* 82: 407–428.
Conway MA, Collins AF, Gathercole SE, and Anderson SJ (1996) Recollections of true and false autobiographical memories. *J. Exp. Psychol. Gen.* 125: 69–95.
Craik FIM and Byrd M (1982) Aging and cognitive deficits: The role of attentional resources. In: Craik FIM and Trehub S (eds.) *Aging and Cognitive Processes*, pp. 191–211. New York: Plenum.
Dab S, Claes T, Morais J, and Shallice T (1999) Confabulation with a selective descriptor process impairment. *Cognit. Neuropsychol.* 16: 215–242.
Danion JM, Gokalsing E, Robert P, Massin Krauss M, and Bacon E (2001) Defective relationship between subjective experience and behavior in schizophrenia. *Am. J. Psychiatry* 158: 2064–2066.
Dodson CS and Johnson MK (1996) Some problems with the process-dissociation approach to memory. *J. Exp. Psychol. Gen.* 125: 181–194.
Dodson CS and Schacter DL (2001) ''If I had said it I would have remembered it'': Reducing false memories with a distinctiveness heuristic. *Psychon. Bull. Rev.* 8: 155–161.
Dunlosky J and Nelson TO (1994) Does the sensitivity of judgments of learning (JOLs) to the effects of various study activities depend on when the JOLs occur? *J. Mem. Lang.* 33: 545–565.
Dunning D, Johnson K, Ehrlinger J, and Kruger J (2003) Why people fail to recognize their own incompetence. *Curr. Dir. Psychol. Sci.* 12: 83–87.
Eich E (1985) Context, memory, and integrated item/context imagery. *J. Exp. Psychol. Learn. Mem. Cogn.* 11: 764–770.
Eich E and Metcalfe J (1989) Mood dependent memory for internal versus external events. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 443–455.
Eich JE (1980) The cue-dependent nature of state-dependent retrieval. *Mem. Cogn.* 8: 157–173.
Eich JE, Weingartner H, Stillman RC, and Gillin JC (1975) State-dependent accessibility of retrieval cues in the retention of a categorized list. *J. Verbal Learn. Verbal Behav.* 14: 408–417.
Fisher RP and Geiselman RE (1992) *Memory-Enhancing Techniques for Investigative Interviewing: The Cognitive Interview*. Springfield, IL: Charles C Thomas Publisher.
Ferguson SA, Hashtroudi S, and Johnson MK (1992) Age differences in using source-relevant cues. *Psychol. Aging* 7: 443–452.
Garry M, Manning CG, Loftus EF, and Sherman SJ (1996) Imagination inflation: Imagining a childhood event inflates confidence that it occurred. *Psychon. Bull. Rev.* 3: 208–214.
Ghetti S (2003) Memory for nonoccurrences: The role of metacognition. *J. Mem. Lang.* 48: 722–739.
Glucksberg S and McCloskey M (1981) Decisions about ignorance: Knowing that you don't know. *J. Exp. Psychol. Hum. Learn. Mem.* 7: 311–325.
Godden DR and Baddeley AD (1975) Context-dependent memory in two natural environments: On land and underwater. *Br. J. Psychol.* 66: 325–331.
Goldsmith M and Koriat A (1999) The strategic regulation of memory reporting: Mechanisms and performance consequences. In: Gopher D and Koriat A (eds.) *Attention and Performance XVII: Cognitive Regulation of Performance: Interaction of Theory and Application*, pp. 373–400. Cambridge, MA: MIT Press.
Goldsmith M, Koriat A, and Pansky A (2005) Strategic regulation of grain size in memory reporting over time. *J. Mem. Lang.* 52: 505–525.
Goldsmith M, Koriat A, and Weinberg Eliezer A (2002) Strategic regulation of grain size memory reporting. *J. Exp. Psychol. Gen.* 131: 73–95.
Goodwin DW, Powell B, Bremer D, Hoine H, and Stern J (1969) Alcohol and recall: State-dependent effects in man. *Science* 163: 1358–1360.
Griffin D and Tversky A (1992) The weighing of evidence and the determinants of confidence. *Cognit. Psychol.* 24: 411–435.
Guynn MJ (2003) A two-process model of strategic monitoring in event-based prospective memory: Activation/retrieval mode and checking. *Int. J. Psychol.* 38: 245–256.
Guynn MJ and McDaniel MA (1999) Generate-sometimes recognize, sometimes not. *J. Mem. Lang.* 41: 398–415.
Hall JF (1990) Reconstructive and reproductive models of memory. *Bull. Psychon. Soc.* 28: 191–194.
Hamm VP and Hasher L (1992) Age and the availability of inferences. *Psychol. Aging* 7: 56–64.
Hasher L and Zacks RT (1988) Working memory, comprehension, and aging: A review and a new view. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 22, pp. 193–225. San Diego, CA: Academic Press.
Hasher L, Zacks RT, and May CP (1999) Inhibitory control, circadian arousal, and age. In: Gopher D and Koriat A (eds.) *Attention and Performance XVII: Cognitive Regulation of Performance: Interaction of Theory and Application*, pp. 653–675. Cambridge, MA: MIT Press.
Higham PA (2002) Strong cues are not necessarily weak: Thomson and tulving (1970) and the encoding specificity principle revisited. *Mem. Cogn.* 30: 67–80.

Higham PA (2007) No special K! A signal detection framework of the strategic regulation of memory accuracy. *J. Exp. Psychol. Gen.* 136: 1–22.
Higham PA and Tam H (2005) Generation failure: Estimating metacognition in cued recall. *J. Mem. Lang.* 52: 595–617.
Higham PA and Tam H (2006) Release from generation failure: The role of study list structure. *Mem. Cogn.* 34: 148–157.
Hilgard ER and Loftus EF (1979) Effective interrogation of the eyewitness. *Int. J. Clin. Exp. Hypn.* 27: 342–357.
Hintzman DL (1987) Recognition and recall in MINERVA2: Analysis of the ''recognition failure'' paradigm. In: Morris P (ed.) *Modeling Cognition: Proceedings of the International Workshop on Modeling Cognition*. London: Wiley.
Israel L and Schacter DL (1997) Pictorial encoding reduces false recognition of semantic associates. *Psychon. Bull. Rev.* 4: 577–581.
Jacoby LL (1991) A process dissociation framework: Separating automatic from intentional uses of memory. *J. Mem. Lang.* 30: 513–541.
Jacoby LL (1999) Ironic effects of repetition: Measuring age-related differences in memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 3–22.
Jacoby LL and Hollingshead A (1990) Toward a generate recognize model of performance on direct and indirect tests of memory. *J. Mem. Lang.* 29: 433–454.
Jacoby LL, Kelley CM, and Dywan J (1989) Memory attributions. In: Roediger III, HL, and Craik FIM (eds.) *Varieties of Memory and Consciousness: Essays in Honour of Endel Tulving*, pp. 391–422. Hillsdale, NJ: Erlbaum.
Jacoby LL, Kelley CM, and McElree BD (1999) The role of cognitive control: Early selection versus late correction. In: Chaiken S and Trope Y (eds.) *Dual Process Theories in Social Psychology*, pp. 383–400. New York, NY: Guilford Press.
Jacoby LL, Shimizu Y, Daniels KA, and Rhodes MG (2005a) Modes of cognitive control in recognition and source memory: Depth of retrieval. *Psychon. Bull. Rev.* 12: 852–857.
Jacoby LL, Shimizu Y, Velanova K, and Rhodes MG (2005b) Age differences in depth of retrieval: Memory for foils. *J. Mem. Lang.* 52: 493–504.
Johnson MK (1997) Identifying the origin of mental experience. In: Myslobodsky MS (ed.) *The Mythomanias: The Nature of Deception and Self Deception*, pp. 133–180. Hillsdale, NJ: Erlbaum.
Jones GV (1989) Back to Woodworth: Role of interlopers in the tip-of-the-tongue phenomenon. *Mem. Cogn.* 17: 69–76.
Kelley CM and Jacoby LL (1996) Adult egocentrism: Subjective experience versus analytic bases for judgment. *J. Mem. Lang.* 35: 157–175.
Kelley CM and Lindsay DS (1993) Remembering mistaken for knowing: Ease of retrieval as a basis for confidence in answers to general knowledge questions. *J. Mem. Lang.* 32: 1–24.
Kelley CM and Rhodes MG (2002) Making sense and nonsense of experience: Attributions in memory and judgment. *Psychol. Learn. Motiv.* 41: 293–320.
Kelley CM and Sahakyan L (2003) Memory, monitoring, and control in the attainment of memory accuracy. *J. Mem. Lang.* 48: 704–721.
Kolers PA and Palef SR (1976) Knowing not. *Mem. Cogn.* 4: 553–558.
Kolers PA and Roediger HL (1984) Procedures of mind. *J. Verbal Learn. Verbal Behav.* 23: 425–449.
Koren D, Seidman LJ, Goldsmith M, and Harvey PD (2006) Real-world cognitive – and metacognitive – dysfunction in schizophrenia: A new approach for measuring (and remediating) more ''right stuff.'' *Schizophr. Bull.,* 32: 310–326.
Koriat A (1993) How do we know that we know? The accessibility model of the feeling of knowing. *Psychol. Rev.* 100: 609–639.
Koriat A (1995) Dissociating knowing and the feeling of knowing: Further evidence for the accessibility model. *J. Exp. Psychol. Gen.* 124: 311–333.
Koriat A (2000) Control processes in remembering. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 333–346. London: Oxford University Press.
Koriat A (2007) Metacognition and consciousness. In: Zelazo PD, Moscovitch M, and Thompson E (eds.) *Cambridge Handbook of Consciousness*, pp. 289–325. Cambridge: Cambridge University Press.
Koriat A and Goldsmith M (1994) Memory in naturalistic and laboratory contexts: Distinguishing the accuracy-oriented and quantity-oriented approaches to memory assessment. *J. Exp. Psychol. Gen.* 123: 297–315.
Koriat A and Goldsmith M (1996a) Memory metaphors and the real-life/laboratory controversy: Correspondence versus storehouse conceptions of memory. *Behav. Brain Sci.* 19: 167–228.
Koriat A and Goldsmith M (1996b) Monitoring and control processes in the strategic regulation of memory accuracy. *Psychol. Rev.* 103: 490–517.
Koriat A and Goldsmith M (1998) The role of metacognitive processes in the regulation of memory accuracy. In: Mazzoni G and Nelson T (eds.) *Metacognition and Cognitive Neuropsychology: Monitoring and Control Processes*, pp. 97–118. Mahwah, NJ: Erlbuam.
Koriat A, Goldsmith M, Schneider W, and Nakash Dura M (2001) The credibility of children's testimony: Can children control the accuracy of their memory reports? *J. Exp. Child Psychol.* 79: 405–437.
Koriat A and Levy-Sadot R (1999) Processes underlying metacognitive judgments: Information-based and experience-based monitoring of one's own knowledge. In: Chaiken S and Trope Y (eds.) *Dual Process Theories in Social Psychology*, pp. 483–502. New York: Guilford Press.
Koriat A, Lichtenstein S, and Fischhoff B (1980) Reasons for confidence. *J. Exp. Psychol. Hum. Learn. Mem.* 6: 107–118.
Koriat A and Lieblich I (1974) What does a person in a ''TOT'' state know that a person in a ''don't know'' state does not know? *Mem. Cogn.* 2: 647–655.
Koriat A and Lieblich I (1977) A study of memory pointers. *Acta Psychol.* 41: 151–164.
Koriat A, Ma'ayan H, and Nussinson R (2006) The intricate relationships between monitoring and control in metacognition: Lessons for the cause-and-effect relation between subjective experience and behavior. *J. Exp. Psychol. Gen.* 135: 36–69.
Koriat A and Melkman R (1987) Depth of processing and memory organization. *Psychol. Res.* 49: 173–181.
Koutstaal W (2003) Older adults encode – but do not always use – perceptual details: Intentional versus unintentional effects of detail on memory judgments. *Psychol. Sci.* 14: 189–193.
Koutstaal W and Cavendish M (2006) Using what we know: Consequences of intentionally retrieving gist versus item-specific information. *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 778–791.
Koutstaal W and Schacter DL (1997) Intentional forgetting and voluntary thought suppression: Two potential methods for coping with childhood trauma. In: Dickstein LJ, Riba MB, and Oldham JM (eds.) *Review of Psychiatry,* vol. 16, pp. II-79–II-121. Washington, DC: American Psychiatric Press.
Kvavilashvili L and Mandler G (2004) Out of one's mind: A study of involuntary semantic memories. *Cognit. Psychol.* 48: 47–94.
Levy BJ and Anderson MC (2002) Inhibitory processes and the control of memory retrieval. *Trends Cogn. Sci.* 6: 299–305.
Lindsay DS (1994) Memory source monitoring and eyewitness testimony. In: Ross DF, Read JD, and Toglia MP (eds.) *Adult*

*Eyewitness Testimony: Current Trends and Developments*, pp. 27–55. NY: Cambridge University Press.
Loftus GR and Wickens TD (1970) Effect of incentive on storage and retrieval processes. *J. Exp. Psychol.* 85: 141–147.
Malmberg KJ (in press). Investigating metacognitive control in a global memory framework. In: Dunlosky J and Bjork RA (eds.) *Handbook of Memory and Metamemory: Essays in Honor of Thomas O. Nelson*. New Jersey: Erlbaum.
Mantyla T (1986) Optimizing cue effectiveness – Recall of 500 and 600 incidentally learned words. *J. Exp. Psychol. Learn. Mem. Cogn.* 12: 66–71.
May CP and Hasher L (1998) Synchrony effects in inhibitory control over thought and action. *J. Exp. Psychol. Hum. Percept. Perform.* 24: 363–379.
Mazzoni G and Kirsch I (2002) Autobiographical memories and beliefs: A preliminary metacognitive model. In: Perfect TJ and Schwartz BL (eds.) *Applied Metacognition*, pp. 121–145. New York, NY: Cambridge University Press.
McKenzie CRM (1997) Underweighting alternatives and overconfidence. *Organ. Behav. Hum. Decis. Process.* 71: 141–160.
McNally RJ (1998) Experimental approaches to cognitive abnormality in posttraumatic stress disorder. *Clin. Psychol. Rev.* 18: 971–982.
Mitchell KJ and Johnson MK (2000) Source monitoring: Attributing mental experiences. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 179–195. New York: Oxford University Press.
Moscovitch M (1989) Confabulation and the frontal systems: Strategic versus associative retrieval in neuropsychological theories of memory. In: Roediger HL, III, and Craik FIM (eds.) *Varieties of Memory and Consciousness: Essays in Honour of Endel Tulving*, pp. 133–160. Hillsdale, NJ: Erlbaum.
Moscovitch M (1994) Cognitive resources and dual-task interference effects at retrieval in normal people: The role of the frontal lobes and medial temporal cortex. *Neuropsychology* 8: 524–534.
Moscovitch M and Melo B (1997) Strategic retrieval and the frontal lobes: Evidence from confabulation and amnesia. *Neuropsychologia* 35: 1017–1034.
Murdock BB (1993) TODAM2: A model for the storage and retrieval of items, associative, and serial order information. *Psychol. Rev.* 100: 183–203.
Naveh-Benjamin M, Craik FIM, Perretta JG, and Tonev ST (2000) The effects of divided attention on encoding and retrieval processes: The resiliency of retrieval processes. *Q. J. Exp. Psychol.* 53A: 609–625.
Neisser U (1967) *Cognitive Psychology*. New York: Appleton-Century-Crofts.
Neisser U (1984) Interpreting Harry Bahrick's discovery: What confers immunity against forgetting. *J. Exp. Psychol. Gen.* 113: 32–35.
Neisser U (1988) Time present and time past. In: Gruneberg MM, Morris PE, and Sykes RN (eds.) *Practical Aspects of Memory: Current Research and Issues*. pp. 545–560. Chichester: Wiley.
Nelson DL, Dyrdal GM, and Goodmon LB (2005) What is preexisting strength? Predicting free association probabilities, similarity ratings, and cued recall probabilities. *Psychon. Bull. Rev.* 12: 711–719.
Nelson DL, McKinney VM, Gee NR, and Janczura GA (1998) Interpreting the influence of implicitly activated memories on recall and recognition. *Psychol. Rev.* 105: 299–324.
Nelson TO and Narens L (1990) Metamemory: A theoretical framework and new findings. In: Bower G (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 26, pp. 125–17. San Diego: Academic Press.
Nelson TO and Narens L (1994) Why investigate metacognition? In: Metcalfe J and Shimamura AP (eds.) *Metacognition: Knowing about Knowing*, pp. 1–25. Cambridge, MA: MIT Press.
Nhouyvanisvong A and Reder LM (1998) Rapid feeling-of-knowing: A strategy selection mechanism. In: Yzerbyt VY, Lories G, and Dardenne B (eds.) *Metacognition: Cognitive and Social Dimensions*, pp. 35–52. Thousand Oaks, CA: Sage.
Nickerson RS (1981) Motivational retrieval from archival memory. In: Flowers JH (ed.) *Nebraska Symposium on Motivation*, pp. 73–119. Lincoln: University of Nebraska Press.
Norman DA and Bobrow DG (1979) Descriptions: An intermediate stage in memory retrieval. *Cognit. Psychol.* 11: 107–123.
Norman KA and Schacter DL (1996) Implicit memory, explicit memory, and false recollection: A neuroscience perspective. In: Reder LM (ed.) *Implicit Memory and Metacognition*, pp. 229–257. Hillsdale, NJ: Erlbaum.
Odegard TN and Lampinen JM (2006) Memory editing: Knowledge, criteria, and alignment. *Memory* 14: 777–787.
Pansky A, Koriat A, Goldsmith M, and Pearlman-Avnion S (2002) Memory accuracy and distortion in old age: Cognitive, metacognitive, and neurocognitive determinants. Poster session presented at the 30th Anniversary Conference of the National Institute for Psychobiology in Israel. Jerusalem, Israel.
Payne BK, Jacoby LL, and Lambert AJ (2004) Memory monitoring and the control of stereotype distortion. *J. Exp. Soc. Psychol.* 40: 52–64.
Perfect TJ (2004) The role of self-rated ability in the accuracy of confidence judgements in eyewitness memory and general knowledge. *Appl. Cogn. Psychol.* 18: 157–168.
Raaijmakers JG and Shiffrin RM (1980) SAM: A theory of probabilistic search of associative memory. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 14, pp. 207–262. New York: Academic Press.
Raaijmakers JG and Shiffrin RM (1981) Search of associative memory. *Psychol. Rev.* 88: 93–134.
Radvansky GA, Zacks RT, and Hasher L (2005) Age and inhibition: The retrieval of situation models. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 60B: P276–P278.
Reason J and Lucas D (1984) Absent-mindedness in shops: Its incidence, correlates and consequences. *Br. J. Clin. Psychol.* 23: 121–131.
Reder LM (1987) Strategy selection in question answering. *Cognit. Psychol.* 19: 90–138.
Reder LM, Wible C, and Martin J (1986) Differential memory changes with age: Exact retrieval versus plausible inference. *J. Exp. Psychol. Learn. Mem. Cogn.* 12: 72–81.
Reiser BJ, Black JB, and Abelson RP (1985) Knowledge structures in the organization and retrieval of autobiographical memories. *Cognit. Psychol.* 17: 89–137.
Reiser BJ, Black JB, and Kalamarides P (1986) Strategic memory search processes. In: Rubin DC (ed.) *Autobiographical Memory*, pp. 100–121. New York: Cambridge University Press.
Rhodes MG and Kelley CM (2005) Executive processes, memory accuracy, and memory monitoring: An aging and individual difference analysis. *J. Mem. Lang.* 52: 578–594.
Robinson MD, Johnson JT, and Herndon F (1997) Reaction time and assessments of cognitive effort as predictors of eyewitness memory accuracy and confidence. *J. Appl. Psychol.* 82: 416–425.
Roebers CM, Moga N, and Schneider W (2001) The role of accuracy motivation on children's and adults' event recall. *J. Exp. Child Psychol.* 78: 313–329.

Roediger HL (1999) Why retrieval is the key process in understanding human memory. In: Tulving E (ed.) *Memory, Consciousness and the Brain – The Tallinn Conference*, pp. 52–75. Philadelphia: Psychology Press.
Ross M (1989) Relation of implicit theories to the construction of personal histories. *Psychol. Rev.* 96: 341–357.
Schacter DL, Israel L, and Racine C (1999) Suppressing false recognition in younger and older adults: The distinctiveness heuristic. *J. Mem. Lang.* 40: 1–24.
Schacter DL, Norman DA, and Koutstaal W (1998) The cognitive neuroscience of constructive memory. *Annu. Rev. Psychol.* 49: 289–318.
Schank RC (1982) *Dynamic Memory*. Cambridge: Cambridge University Press.
Schwartz BL and Metcalfe J (1992) Cue familiarity but not target retrievability enhances feeling-of-knowing judgments. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 1074–1083.
Smith RE and Hunt RR (1998) Presentation modality affects false memory. *Psychon. Bull. Rev.* 5: 710–715.
Smith SM (1979) Remembering in and out of context. *J. Exp. Psychol. Hum. Learn. Mem.* 5: 460–471.
Smith SM, Glenberg A, and Bjork RA (1978) Environmental context and human memory. *Mem. Cogn.* 6: 342–353.
Smith SM and Vela E (2001) Environmental context-dependent memory: A review and meta-analysis. *Psychon. Bull. Rev.* 8: 203–220.
Srinivas K, Rajaram S, and Roediger HL (1998) A transfer-appropriate processing account of context effects in word fragment completion. *J. Exp. Psychol. Learn. Mem. Cogn.* 24: 993–1004.
Strack F (1992) The different routes to social judgments: Experiential versus informational strategies. In: Martin LL and Tesser A (eds.) *The Construction of Social Judgments*, pp. 249–275. Hillsdale, NJ: Erlbaum.
Strack F and Bless H (1994) Memory for nonoccurrences: Metacognitive and presuppositional strategies. *J. Mem. Lang.* 33: 203–217.
Suengas AG and Johnson MK (1988) Qualitative effects of rehearsal on memories for perceived and imagined complex events. *J. Exp. Psychol. Gen.* 117: 377–389.
Thomson DM and Tulving E (1970) Associative encoding and retrieval: Weak and strong cues. *J. Exp. Psychol.* 86: 255–262.
Tulving E (1976) Ecphoric processes in recall and recognition. In: Brown J (ed.) *Recall and Recognition*, pp. 37–73. Oxford: Wiley.
Tulving E (1983) *Elements of Episodic Memory*. Oxford: Clarendon Press.
Tulving E and Pearlstone Z (1966) Availability versus accessibility of information in memory for words. *J. Verbal Learn. Verbal Behav.* 5: 381–391.
Tulving E and Thomson DM (1973) Encoding specificity and retrieval processes in episodic memory. *Psychol. Rev.* 80: 359–380.
Walker WH and Kintsch W (1985) Automatic and strategic aspects of knowledge retrieval. *Cogn. Sci.* 9: 261–283.
Weldon MS and Colston HL (1995) Dissociating the generation stage in implicit and explicit memory tests – Incidental production can differ from strategic access. *Psychon. Bull. Rev.* 2: 381–386.
Whittlesea BWA (2002) Two routes to remembering (and another to remembering not). *J. Exp. Psychol. Gen.* 131: 325–348.
Whittlesea BWA and Williams LD (2001a) The discrepancy-attribution hypothesis: I. The heuristic basis of feelings and familiarity. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 3–13.
Whittlesea BWA and Williams LD (2001b) The discrepancy-attribution hypothesis: Ii. Expectation, uncertainty, surprise, and feelings of familiarity. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 14–33.
Williams MD and Hollan JD (1981) The process of retrieval from very long-term-memory. *Cogn. Sci.* 5: 87–119.
Williams MD and Santos-Williams S (1980) Methods for exploring retrieval processes using verbal protocols. In: Nickerson RS (ed.) *Attention and Performance,* vol. VIII, pp. 671–689. Hillsdale, NJ: Erlbaum.
Wiseman S and Tulving E (1976) Encoding specificity: Relation between recall superiority and recognition failure. *J. Exp. Psychol. Hum. Learn. Mem.* 2: 349–361.
Yaniv I and Foster DP (1995) Graininess of judgment under uncertainty: An accuracy–informativeness trade-off. *J. Exp. Psychol. Gen.* 124: 424–432.
Yaniv I and Foster DP (1997) Precision and accuracy of judgmental estimation. *J. Behav. Decis. Making* 10: 21–32.
Yates JF, Lee JW, Sieck WR, Choi I, and Price PC (2002) Probability judgment across cultures. In: Gilovich T, Griffin D, and Kahneman D (eds.) *Heuristics and Biases: The Psychology of Intuitive Judgment*, pp. 271–291. New York: Cambridge University Press.

# 2.19 Source Monitoring

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People sometimes experience difficulty identifying the origins of their thoughts, images, and feelings. You might, for example, find yourself wondering 'Where did I get the idea that the U.S. Speaker of the House is third in line to the presidency?' or 'Did I turn off the oven before I left the house, or did I only think about turning it off?' Moreover, people sometimes erroneously attribute thoughts, images, and feelings to origins other than the true sources. Victims of cryptomnesia (unconscious plagiarism), for example, experience memory-based thoughts as new ideas (Brown and Murphy, 1989; Marsh et al., 1997; Stark and Perfect, 2006). In déjà vu, in contrast, a person has the subjective experience of recognizing a current situation as familiar without having experienced a directly corresponding prior episode (Brown, 2004).

The source monitoring framework (SMF) is an evolving collection of ideas designed to explain the mechanisms by which people attribute mental events to particular origins (Johnson et al., 1993; Johnson, 2006). It is referred to as a framework, rather than a theory or model, in acknowledgment of the fact that the approach stops far short of fully specifying or formalizing the mechanisms involved in identifying the sources of mental events. The core thesis of the SMF is that thoughts/images/feelings that come to mind do not include abstract tags or labels that name their sources, but rather have qualitative and quantitative characteristics that are more or less diagnostic of source. As elaborated in the following, mental events are said to be attributed to particular sources on the basis of their characteristics in the context of the individual's current orientation.

Source is a multidimensional construct that refers to the various dimensions that collectively specify how one came to have a particular mental experience. Dimensions of the sources of memories include spatial/environmental context, temporal context, modality of apprehension (e.g., whether a remembered sentence was heard or read or merely imagined), and agent (e.g., who said a remembered utterance). Thus the concept of memory for source is similar to what Brown and Kulik (1977), in their exploration of flashbulb memories, termed memory for circumstances of encounter (e.g., your recollections of learning of the 9/11 attacks on the World Trade Center).

The construct of source is also similar to (but more inclusive than) that of memory for context. Some models of memory make a sharp distinction between memory for content and memory for context, characterizing the latter as an abstract tag or label that is associated with but not intrinsic to the memorial representation of content (Anderson and Bower, 1974; Murnane et al., 1999). Such models constrain the range of potential contexts quite narrowly (e.g., List 1 vs. List 2). In the SMF, in contrast, the distinction between content and source is a blurry one, sources are thought to be inferred from multiple aspects of the accessed memorial information itself rather than read off from a tag, and the range of potential sources is unbounded.

## 2.19.1 Underlying Assumptions Regarding Basic Mechanisms of Memory

The SMF is not in itself an account of encoding/retention/revival of memory information, but it rests on certain assumptions about how memory works (see Johnson, 1985). Space constraints prohibit a detailed exegesis here, but it is worthwhile briefly summarizing some key points. One such assumption is that memory traces or records are by-products of the multiple cognitive operations that underlie and give rise to ongoing experience. It follows that memory traces for any given event are distributed across multiple processing subsystems. Reading a word, for example, involves a host of cognitive processes, from relatively low-level, data-driven, automatic, generic processes (e.g., figure/ground separation, identifying letter and word shapes, etc.) to higher-level, more conceptual, abstract, effortful, and instance-specific processes (e.g., noting a conceptual relationship between a study word and an earlier word on the list). All such processes have lasting effects on the processing subsystems that perform them (memory traces), as per connectionist models of memory (McClennand and Rumelhart, 1985; McClelland et al., 2003; see also Kolers and Roediger, 1984).

The SMF assumes that the revival of information from memory follows the transfer-appropriate processing (TAP; Morris et al., 1977) or encoding specificity principle (ESP; Tulving and Thompson, 1973), as in Tulving's ideas about synergistic ecphory (Tulving, 1984). Ongoing processes that are sufficiently and distinctively similar to past processes cue revival of those past processes. Importantly, some aspects or features of the processes that gave rise to and constitute a past episode can be revived without other aspects or features being revived. A cue might bring to mind information about the spatial location of a previously presented stimulus, for example, but not information about its color. Or one might recollect relatively abstract, conceptual aspects of a past experience without remembering surface-level details of that experience (e.g., one might remember that a previously presented word was a taboo word but not remember the exact word) (cf. Brainerd and Reyna, 1990).

Several factors influence which features of a past event are, versus are not, revived by a cue. For one, cognitive processes vary in the extent to which they produce distinctive traces of the sort likely subsequently to be experienced as recollections of a specific prior episode. Highly automatic, low-level, data-driven processes are rarely consciously experienced in ongoing experience, and they tend to be executed in much the same way each time they are engaged. Thus records of any particular instance of such processing cannot readily be cued (cue overload) and in any case their revival would not directly give rise to thoughts or images per se because their initial performance did not give rise to thoughts or images. That is, processes that are tacit and unconscious in ongoing experience are tacit and unconscious when later cued, although the influence of such memory traces can be detected under some conditions, such as in measures of repetition priming involving transformed text or highly unusual fonts (Kolers and Roediger, 1984; Wiggs and Martin, 1994; Westerman et al., 2003).

Another determinant of which aspects of a past experience are versus are not revived by a cue is the nature of the cue, as per TAP/ESP. For example, memories of prior sensory processes are more likely to be revived by representation of the perceptual stimulus than by a more abstract cue. Being oriented toward remembering – what Tulving (1998) called being in retrieval mode – can be described in TAP terms as a matter of configuring aspects of current thought in ways that more effectively act as cues for past thoughts. Finally, which aspects of a past event are revived in response to a cue is influenced by the extent to which different aspects of the initial event were bound together with one another, which in turn reflects attention during and shortly after the event. Aspects of an event that are in the focus of attention and that are reflected upon as or immediately after they occur tend to be bound together in ways that support revival of aspect X in response to a cue that maps on to aspect Y (Johnson et al., 2005). Refreshing newly created memories by reflecting on recently experienced events may also be involved in memory consolidation (Wixted, 2004).

Cues rarely if ever revive only memory information from a single to-be-remembered prior episode. Rather, cues evoke episodic information from multiple past events that are similar in various ways to the cues (cf. Neisser's 1981 concept of "repisodes"), along with more abstract knowledge and beliefs conceptually related to the cues. Thus schema and scripts, biases, expectations, stereotypes, etc., are evoked by cues in parallel with episodic details when we remember the past. The memory system must work in such a way that cues evoke memory information from multiple episodes combined with more general knowledge, because otherwise we could only retrieve memories of event X by way of extremely X-specific cues. If the system gave us only exactly what we were looking for, we would have to be able to specify very precisely what it is we are looking for. Of course, if we knew exactly what information we sought from memory there would be no need to look for it. Thus we need a sophisticated set of source monitoring processes not only to specify the sources of a particular memory record but also to help us differentiate between recollections of the multiple episodes, repisodes, inferences, schemas, etc., that come to mind in response to internally and externally generated cues.

The SMF also assumes that reviving memory information itself leaves traces. That is, when a person recollects a past event she creates memories of that episode of recollection. Cues that are effective for reviving the event itself are also likely to be effective for reviving such memories of remembering (Lane et al., 2001). After multiple instances of recollecting a particular past event, the revival of memories of the prior recollections may come to dominate those of the event itself. Relatedly, the way a person talks about his or her memories of an event can influence subsequent recollections of that event (Higgins and Rholes, 1978; Marsh and Tversky, 2004; Echterhoff et al., in press). Reviving memories also appears to strengthen the binding between different aspects of the remembered event (i.e., those aspects that are revived; Johnson, 1994); again, binding is key to the episodic, autonoetic quality of remembering (i.e., the subjective experience of partially reliving a prior experience in one's personal past).

## 2.19.2 Johnson and Raye's Reality Monitoring Model

The SMF is an outgrowth and elaboration of Johnson and Raye's (1981) reality monitoring (RM) model. The RM model was primarily an account of how individuals differentiate between memories of actual perceptual events versus memories of thoughts, fantasies, or dreams (e.g., 'Did I lock the door, or did I only think about locking the door?'). The RM model emphasized the role of average quantitative differences between memories of actual versus imagined events. The model posited, for example, that memories of actual experiences tend, on average, to be more perceptually detailed than memories of imagined events and hence that amount of perceptual detail serves as a cue to a memory's reality status: Perceptually detailed memories probably really happened, whereas perceptually vague memories were probably merely imagined. As another example, the RM model held that memories of imagined events typically include more traces indicating effortful, internally generated cognitive operations (i.e., the mental processes involved in deliberately imagining the event), and hence that amount of memorial evidence of cognitive operations serves as a cue for differentiating between memories of actual versus imagined events.

According to the RM model, perceptually rich memories with little indication of effortful cognitive operations are likely to be experienced as memories of actual events. Thus, for example, a memory of an unusually vivid and fluently generated fantasy is likely to be misidentified as a memory of an actual event. The RM model also includes a more reflective, systematic process that can be engaged when memories with intermediate quantitative characteristics come to mind. Those more analytical processes use knowledge and beliefs to make deliberative inferences about the reality status of a remembered event based on its content (e.g., 'It must be that I really did give that message to Sara, because if I hadn't she would have called me by now'). Such systematic processes may also be engaged when the qualitative content of a memory contradicts the reality status implied by its quantitative characteristics. A vivid memory of unaided flight, for example, might initially be classified as a memory of a real event by rapid, heuristic processes based on quantitative characteristics, but then be reclassified as a memory of a dream or fantasy based on the rememberer's belief that people cannot fly.

Johnson and her coworkers amassed a considerable body of evidence in support of the RM model. For example, participants rated their memories of past fantasies as less perceptually detailed than their memories of past real events, and when asked why they believed a particular memory was of a real versus imagined event, they often cited such characteristics (Johnson et al., 1988b). As another example, subjects were more likely to confuse memories of seeing line drawings with memories of imagining line drawings if the objects were easily imaged than if they were difficult to image (Finke et al., 1988).

The SMF incorporates the ideas of the RM framework, but as explained below it differs from it in two major ways. First, the SMF assumes that the quantitative characteristics of memories (e.g., amount of perceptual detail) constitute only a small subset of a broad range of memorial characteristics that can be used quickly and automatically to attribute thoughts, images, and feelings to particular sources of past experience. Second, rather than dichotomizing between internally generated and physically instantiated events, the SMF seeks to account for an unbounded range of finer-grained source identifications that, collectively, specify all dimensions of a mental event's origin.

## 2.19.3 Memory Source Monitoring

### 2.19.3.1 Basic Mechanisms

As noted, the key premise of the SMF is that the sources of memories are rarely abstractly specified (named or labeled) in the memorial contents whose revival is prompted by a cue. This follows from the assumption that memory traces are by-products of ongoing cognitive processes, and from the corollary that individuals only occasionally reflect on and label the various dimensions of the source of ongoing events. As you read the preceding paragraph, for example, you probably were not thinking, 'I'm reading Steve Lindsay's chapter in Roddy Roediger's handbook at time X on date Y in place Z.' What is tacit in ongoing experience will be tacit in memory records. Consequently, even if the full wealth of cognitive processes performed during a particular past event could be revived, they would probably not abstractly label or specify many source dimensions.

According to the SMF, the processes by which memories are attributed to sources are analogous to those by which aspects of perceptual events are attributed to particular sources in ongoing experience (see also Payne and Blackwell, 1998). If your friend Kathy calls you on the phone, when she says 'Hello' you recognize her voice; the auditory signal does not include any abstract designation of the speaker's identity, but processing the sounds evokes the information that leads you to hear it as Kathy's voice. In both the perceptual and memorial cases, source attributions are usually made very quickly, with little if any conscious awareness of a decision-making process and with very high levels of accuracy. But various conditions can undermine source attributions, making them more difficult and error prone.

One source of difficulty in memory source attributions is sparse revival of memorial information. This is analogous to the difficulty you might have in recognizing a friend's voice on the phone if the connection was bad. In the memorial case, sparse revival may be due, for example, to poor attention during the event itself or to poor cuing (e.g., cues that only partially map onto the to-be-remembered past event and/or that also map on to numerous other past events (cue overload)). Thus, various manipulations that impair encoding or retrieval of source-specifying aspects of an event tend to lower source monitoring performance. Troyer et al. (1999), for example, showed that performing a finger-tapping task during study substantially lowered SM accuracy (more than it lowered recognition). Similarly, Zaragoza and Lane (1998) showed that subjects who encountered or retrieved misleading suggestions under divided attention were more likely to later make false-memory reports consistent with those suggestions than were subjects who encountered or retrieved them under full attention (see also Lane, 2006).

Memory source attributions are also compromised when two or more sources of prior experience are highly similar to one another. If your friends Kathy and Francine have very similar voices, then you may misidentify a recollected utterance of Kathy's as having been made by Francine, just as you might confuse Kathy's voice with Francine's on the phone. In a breakthrough study by Johnson et al. (1988b), subjects heard an experimenter say some words and imagined other words, and later attempted to remember which words had been spoken and which had been imagined. Subjects who had been instructed to imagine the words in their own voice were substantially more accurate than were those who had been instructed to imagine the words in the experimenter's voice (even though old/new recognition was equivalent in those two conditions). I term this a breakthrough study because, to the best of my knowledge, it was the first in which the sources could only be differentiated on the basis of qualitative content (e.g., remembered sound of voice) as opposed to quantitative characteristics (e.g., amount of sensory detail). As another example along the same lines, participants in a study by Lindsay et al. (1991) watched a video in which two individuals took turns telling a story about going to the circus; subjects were later tested on their ability to identify which of the storytellers had mentioned particular details. Performance was substantially poorer when both storytellers were teenaged girls than when one storyteller was a teenaged girl and the other was an elderly man. Presumably, memories of the appearance and sound of the two speakers were more diagnostic of source when the two storytellers were dissimilar on those dimensions.

Effects of source similarity on subsequent SM are not limited to perceptual similarity; semantic or conceptual similarity can also reduce SM discrimination. For example, in the Lindsay et al. (1991) study, subjects more often failed to remember which storyteller had talked about a particular detail (e.g., that the sword swallower wore black boots) if both storytellers had said something about that circus act than if only one of them had said anything about that act.

As one might expect given the analogy to perception, source monitoring attributions can be influenced by expectations and stereotypes held by the rememberer. For example, Marsh et al. (2006) found that stereotypically masculine statements were more likely to be attributed to a male speaker and stereotypically feminine statements to a female speaker. Similarly, Mather et al. (1999) found that subjects tended to attribute remembered utterances to speakers whose political views fit those utterances. Spaniol and Bayen (2002) found that SM judgments were more likely to be influenced by schemas when memory was relatively poor, just as expectations are more likely to distort perception of vague or ambiguous stimuli than strong and clear ones.

Another sort of bias, termed the it-had-to-be-you effect, is the tendency to attribute false memories to whichever source tends to give rise to weaker memories. In an experiment by Johnson et al. (1981), for example, subjects listened to the experimenter say some words and generated words of their own; on a later test, when they falsely recognized a word, they tended to say that the experimenter, rather than themselves, had generated that word. Presumably, memories of nonpresented words tend to be fairly vague and weak, biasing subjects toward assuming that they came from whichever source tends to give rise to weaker memories. In the first of a clever pair of studies, Hoffman (1997) set up a situation in which recognition memory was better for items that subjects had been asked to imagine in an initial phase than for items they had perceived; when subjects false-alarmed to a nonstudied item, they tended to classify it as having been perceived. In Hoffman's second experiment, phase 1 was changed in ways that led memory to be better for perceived than for imagined items, which in turn reversed the direction of the bias: Now when subjects false-alarmed they tended to attribute those memories to imagination rather than perception. Bink et al. (1999) provided evidence and arguments to the effect that such biases are not necessarily based on strength *per se*: Rather, subjects are biased to attribute false memories to whatever source has characteristics that resemble those of false memories.

In a related phenomenon, people often report phenomenological qualities of false memories that correspond to the characteristics of the source to which the person erroneously attributes those memories. For example, Mather et al. (1997) had subjects listen to audio recordings of Deese/Roediger/McDermott (DRM) lists read by different voices. Such lists consist of words that are all backward associates of a critical word that is not, itself, included in the list (e.g., bed, rest, awake, tired, etc., for the critical word sleep), and subjects very often falsely remember the nonpresented critical lure. If one speaker read all of the words in each list, then when subjects false-alarmed to critical lures they were very likely to attribute their memories of the lure to the associated list (for analogous findings, see Lampinen et al., 1999; Gallo et al., 2001; Roediger et al., 2004).

As noted earlier, variables that impair encoding often compromise SM. But under some conditions superior encoding can promote SM errors. For example, Toglia et al. (1999) found that deep as opposed to shallow processing of DRM items increased correct recall but also increased false recall. Likewise, Gallo and Roediger (2003) found that elderly adults did more poorly than younger adults on remembering the source of studied DRM items, and that this age-related decline in source memory had the salutary effect of reducing the tendency to attribute false memories of critical lures to the associated list. Similarly, Lyle et al. (2006) found that elderly adults were less able to remember the spatial locations in which images had been presented for study and that they were less likely to falsely claim to have studied look-alike foils in those locations. In all of these cases, the processes that promote accurate recollection also tend to promote illusory recollection.

Under some conditions, processes that enhance memory for studied items also serve to differentiate memories of studied versus nonstudied items and hence to lower the incidence of false memories. Dodson and Schacter (2002), for example, had subjects study a list of words or a list of pictures, then tested their recognition memory with words. Some new (nonstudied) test words were repeated on the test with various lags (as per Jennings and Jacoby, 1997). Subjects who had studied items as pictures were substantially less likely to false-alarm to repetitions of new items on the test than were subjects who had studied items as words, presumably because having studied pictures led subjects to expect that they would be able to recollect pictorial information in response to test probes corresponding to studied words.

Instructions to attend to memory sources, or warnings about potential source monitoring confusions, usually reduce the likelihood of such errors. Presumably such instructions encourage individuals to engage more deliberative, systematic source monitoring processes, rather than relying on quick and easy but more error-prone source monitoring heuristics. Under conditions that encourage lax source monitoring, subjects may endorse almost any item that seems familiar, whereas under other conditions subjects may take care to disentangle different sources of familiarity. For example, Lindsay and Johnson (1989) tested subjects in a variant of Loftus's eyewitness misinformation procedure (e.g., Loftus et al., 1978). Subjects viewed an event, were exposed to misleading suggestions regarding some details in that event, and were then tested on memory for the event. Those tested with a yes/no recognition memory test very often falsely responded Yes to test items that referred to details that had been suggested but not witnessed. Subjects tested on a SM test, in contrast, rarely claimed to have seen in the event things that had merely been suggested, presumably because the SM test encouraged subjects explicitly to query their memories of each item to differentiate between different sources of familiarity (cf. Zaragoza and Koshmider, 1989; Echterhoff et al., 2005). Similarly, manipulations that make the source of misleading suggestions more salient and memorable tend to reduce SM errors (e.g., Sharman et al., 2005).

Source attributions can be made at a wide range of degrees of precision or grain size (e.g., Schacter et al., 1984; Dodson et al., 1998). You might, for example, remember that a statement was made by a woman rather than by a man, perhaps even that the statement was made by a woman student in one of your classes last week, without being able to identify the speaker. The specificity of source attributions is partly a matter of the accessible memory information; the information revived about a past event is often sufficient only for a relatively crude level of source monitoring. Also, within the limits of the accessible memorial information, the specificity of source attributions is flexibly tuned to the rememberer's current goals. Oftentimes people are not concerned about precisely specifying the sources of the thoughts and images that come to mind. In telling an anecdote at a social gathering, for example, one may babble along, interweaving recollections of the to-be-related episode with memories of other prior experiences and memories of stories told by others, filling in weak spots in the narrative with inferences, and enlarging the fish that got away without being aware of doing so, because one's objective is to be entertaining rather than to monitor the origins of one's material.

Most SM attributions are made quickly and without conscious reflection (again, just as is the case with most identifications in ongoing perception). But sometimes rapid, heuristic SM processes fail to produce a source attribution at the appropriate grain size, and the rememberer has a subjective experience of being unable to specify a memory's source. In such cases the individual may bring more consciously controlled reflective strategies to bear. One such strategy is deliberatively cuing memory in different ways in an effort to retrieve additional source-specifying details. Another is to retrieve memories that are associated with the memory in question (e.g., memories of what happened before or after the event in question, or memories of other events involving the same agent or context as the memory in question). The use of memories of associated events to guide deliberative SM judgments has not received much study, but there is evidence that subjects report more memories of preceding and succeeding events for memories of actual events than for memories of imagined events (Johnson et al., 1988b). Intuition suggests that memories of associated events play major roles in resolving SM failures. Yet another deliberative SM strategy is reasoning (e.g., inferring when an event occurred on the basis of the idea that causes precede effects).

### 2.19.3.2 Source Monitoring Versus Old/New Recognition

As has long been noted, most laboratory studies of recognition memory are essentially tests of SM, because both studied and nonstudied stimuli are familiar to subjects from extraexperimental sources. Such tests require subjects to discriminate between items encountered extraexperimentally and in the study list versus items encountered extraexperimentally but not in the study list (Anderson and Bower, 1972). Moreover, even when novel stimuli are used, subjects at test must discriminate between reactions to stimuli that stem from having encountered those stimuli on the study list versus those that arise for other reasons (e.g., ease of processing the test probes; Whittlesea, 1993, 2002).

In a typical SM experiment, subjects study items from two sources and are later tested on a mixture of items from Source A, items from Source B, and new items. Thus performance can be assessed in terms of old/new discrimination (i.e., proportion old recognized as old regardless of source-identification accuracy) and in terms of SM accuracy (e.g., proportion of old items recognized as old correctly attributed to source). In most such situations, SM accuracy requires a finer grain of memory specificity than does old/new recognition, simply because Sources A and B are nested within the set of old items. Thus correctly recognizing an item as being from a particular source within the experiment generally requires a finer level of detail than does recognizing an item as having been presented in one source or another in the experiment.

Because of this characteristic difference in grain size, SM is sometimes sensitive to variables that do not significantly affect old/new recognition accuracy. For example, relative to healthy young adults' performance, poorer SM but equivalent old/new recognition may be observed in young children (Foley and Johnson, 1985; Lindsay, 2002), elderly adults (McIntyre and Craik, 1987; Hashtroudi et al., 1999), and amnesics (Shimamura and Squire, 1987). Similarly, under at least some conditions, dividing attention at study has larger effects on SM than on old/new discrimination (e.g., Frost et al., 2002; Castel and Craik, 2003).

It is possible to contrive situations in which conditions that lead to inferior old/new recognition lead to superior SM. Subjects in a study by Lindsay and Johnson (1991), for example, saw a series of words, some presented on the right and others on the left. Half the subjects performed a relatively deep orienting task for words on the right and left, whereas others performed a deep task for words on one side and a shallow orienting task for words on the other side. As one would expect, old/new recognition was poorer among subjects who studied half of the items with a shallow task than among subjects who studied all of the items with a deep task. But because memory for orienting task provided a potent cue for source discrimination among subjects who studied half of the items with a shallow task, those in that condition had higher SM scores than those who studied all of the items with a deep task.

Despite such dissociations, the SMF holds that old/new recognition judgments and SM judgments generally have much in common. In many laboratory tasks, memory information that indicates that an item came from source X also constitutes evidence that the item is old. To the extent that two judgments draw on the same information, performance on them will be correlated (Glanzer et al., 2004; Johnson, 2005).

### 2.19.3.3 Measures of Source Monitoring

In many studies, SM has been indexed as the proportion of old items recognized as old that are also correctly attributed to source (sometimes called an identification of origin or IDO score). For example, given two sources, A and B:

$$(A|A + B|B)/(A|A + B|B + A|B + B|A)$$

where A|A means that the subject responds A when given an item from source A, etc. One limitation of this measure is that it is likely to be inflated by guessing. Another is that it assumes that SM is equivalent for items from sources A and B, which is not necessarily the case. Yet another concern is that the IDO score implies that SM discrimination and old/new recognition are independent; put differently, the IDO score may confound old/new discrimination and source discrimination.

As a solution to these problems, Batchelder and Riefer (1990) introduced a multinomial model of SM that yields measures of sensitivity and bias for both old/new recognition and source attribution. They and others subsequently elaborated on the multinomial approach, offering a variety of multinomial models for old/new discrimination and source discrimination (Batchelder et al., 1994; Bayen and Murname, 1996; Meiser, 2005). Taking a different approach to the same problems, Banks (2000) developed a multidimensional signal detection model to assess sensitivity and bias for both old/new discrimination and source attribution, since built upon and supported by others (Glanzer et al., 2004). Yonelinas (1999) proposed a model in which recognition without source identification (i.e., familiarity) is described as a signal detection parameter, whereas source identification is assumed to rely on a threshold recollection process (see Qin et al., 2001; Parks and Yonelinas, 2007; Wixted, 2007, for comments on the Yonelinas model). My hunch is that source identification or recollection tends to behave like a threshold process when the materials and procedures are such that source discrimination relies on generation of a very narrow range of kinds of memory information (i.e., on any given trial, a subject will either generate that information or not), whereas in situations in which source can be correctly identified on the basis of numerous different kinds of information, source identification will behave more like a signal detection parameter.

There are no theory-free measures of memory for source (nor, for that matter, of memory without source identification; cf Jacoby et al. 1997). Moreover, there is no one true measurement model that applies in all situations (Meiser, 2005). Rather, the best measure will rely on the specifics of the situation, depending on factors such as the extent to which identification of sources A and B relies on the same sorts of memory information. Pending a more complete understanding of memory, it may be that the best approach is to compare a variety of measures; often they converge quite closely, and when they do not, the disparities have the potential to be illuminating. Note that I am not suggesting that researchers try all measures and then report only the one that best supports their biases.

### 2.19.3.4 Time Course of Source Monitoring

On average, coarser source discriminations can be made more quickly than finer ones. When a recognition probe is presented, information that enables the subject to recognize the item as familiar from the experiment typically comes to mind more quickly than information that enables the subject to identify the specific source within the experiment (Johnson et al., 1994). This may simply be due to the fact, noted earlier, that specific within-experiment sources are nested within the larger category of items presented during the experiment, and hence on average require a finer grain size. These time course effects may contribute to the finding that various types of memory errors are more common when subjects are given little time to respond (Dodson and Hege, 2005; Jones, 2006). Such findings have sometimes been described as evidence for a sharp dichotomy between a fast familiarity process and a slow recollection process (McElree et al., 1999), but as noted earlier the SM perspective describes familiarity and recollection as *ad hoc* categories of memory influences rather than as discrete memory systems.

The SMF does not assume an invariant two-stage process in which items are first recognized as old and then attributed to particular sources. It sometimes occurs that an item is initially recognized as old and then attributed to a particular source, but on other occasions an item might first be identified as coming from a particular source (e.g., speaker A) and on that basis experienced as old. Multinomial models appear to imply a two-stage process, but such models are analytic tools, not processing models.

### 2.19.3.5 Temporal Source Monitoring

Among the most common real-world SM failures and confusions are those involved in situating a remembered event in time. 'Was it yesterday or the day before that Justin dropped off the key? Was that before or after Myta called?' 'When I had my tonsils out and stayed home from school eating Jello, was it fall, winter, or spring?' There are literatures on various aspects of memory for temporal information, including a large body of work on serial recall (Anderson and Matessa, 1997), studies of memory for duration (Yarmey, 2000), and research on dating public and personal events (Brown et al., 1986; Burt, 1993; Berntsen and Rubin, 2004; Friedman, 2004; Lee and Brown, 2004). But as far as I know, there has been no empirical work on temporal memory explicitly grounded in a SM perspective.

The SMF suggests that qualitative and quantitative aspects of accessed memory information may provide cues as to when a remembered event occurred. Thus, a recollection of something happening while you were sitting at your breakfast table might be identified as an event that happened in the morning; memories of a snowball fight would likely be attributed to winter. Just as with other attributes of source, such cues can be misleading: perhaps, for example, the snowball fight took place in July in the mountains.

Dating remembered events poses special problems for SM because the contents of event memories usually provide only very indirect cues to the date. If, for example, you once had an accident driving to work, years later you might still be able to recall many details of that experience because of its distinctiveness and salience, and those memories might enable you to specify the location of the accident, the approximate time of day (e.g., driving to vs. from work, in light or darkness), and even perhaps the season (rain or snow), but the memory records probably will not provide direct cues to the date on which the accident occurred. The memories constrain the date (e.g., if you retrieve information about geographical location, and you traveled that route only during a particular period), but such constraints tend to be imprecise (except for memories of events intrinsically associated with particular dates).

Consistent with these ideas, people generally have difficulty dating autobiographical events. For example, Friedman (1987) interviewed people 9 months after a major earthquake: On average, respondents were correct to within 1 h in their judgments of the time of day the earthquake occurred but erred by nearly 2 months in their judgment of the month (see also Thompson et al., 1996; for work on the development of temporal SM, see Friedman and Lyon, 2005).

Repeated experiences of highly similar events increase the difficulty of specifying the date on which a particular instance occurred. On which birthday did you receive that blue sweater? Such a question is likely to cue multiple birthdays, each sharing numerous features and none easily dated, such that they tend to blend together in recollection (into what Neisser, 1981, termed repisodes). Relatedly, Connolly and Lindsay (2001) found that children were more susceptible to misleading suggestions regarding variable details about an event they had experienced on several occasions.

### 2.19.3.6 Affect and Source Monitoring

Emotional arousal tends to enhance memory for occurrence but to impair memory for source. For example, Johnson et al. (1996) showed subjects videos of individuals making emotionally evocative and neutral statements, with instructions that either oriented the subjects to their own affective responses or to those of the speaker. Focusing on one's own emotional responses improved recognition of spoken statements on a subsequent test, but it impaired the ability to remember which speaker had made which statements.

In a more recent study using a short-term source task, Mather et al. (2006) found better item recognition for emotional than for neutral pictures, but better memory for the pictures' spatial locations for neutral than for emotional pictures. Emotionally evocative materials may encourage a narrowing of attention that undermines the binding together of the evocative item and its surrounding context (as per weapon focus; Mitchell et al., 1998).

Orienting toward one's emotions during an event does not always impair subsequent SM. In the Johnson et al. (1996) study just described, for example, shifting the self-focus from how participants felt about the statements to how participants felt about the individual speakers eliminated the self-focus deficit. Although I am not aware of any study testing the hypothesis, it is likely that if a particular emotion was diagnostic of a source, then emotion would be a basis for veridical SM. Nonetheless, in many situations stimuli that evoke strong emotional responses shift attention away from external details that might subsequently be useful for SM.

### 2.19.3.7 Developmental Changes in Children's Source Monitoring

Children as young as 5 years (and probably younger) can do as well as adults on SM tasks in which the sources are quite dissimilar (even when performance for all age groups is below ceiling). But when the sources in a particular situation are highly similar, then younger children do more poorly than adults. For example, seminal studies by Foley and Johnson and coauthors showed that 5-year-olds were as accurate as adults at remembering which of two actors had performed particular actions, but had more difficulty than adults discriminating between memories of actions they had performed versus memories of actions they had imagined themselves performing (Foley et al., 1983; Foley and Johnson, 1985; Foley et al., 1989). Presumably the cognitive processes involved in performing and imagining oneself performing an action are highly similar, and hence memory records of those two types of events are difficult to discriminate. Consistent with this account, Lindsay et al. (1991) found that young children also had more difficulty than older children when discriminating between memories of what they had seen another person do and memories of what they had imagined that person do.

In more recent research, Foley and coauthors found that, after taking turns with the experimenter to add pieces to a collage or model, preschoolers showed a pronounced tendency to remember themselves as having made contributions that were actually made by the experimenter (Foley and Ratner, 1998; Foley et al., 2002). Foley and coauthors proposed that this is at least in part due to children spontaneously anticipating their collaborator's actions; memories of such self-generated anticipations would be highly similar to, and hence easily confused with, memories of having performed actions.

Why do preschoolers make more errors on difficult SM tasks than older children or adults? It is possible that young children imagine events more vividly than do older children, and hence that their memories of imagined and actual events are inherently more confusable than the memories of older children (especially when real and imagined events are performed by the same agent). It is also likely that the memorial information automatically generated in response to test probes becomes more source-specifying with age (i.e., older children recollect more details, including source-specifying ones; e.g., Sluzenski et al., 2006). My hunch, though, is that the primary source of this age difficulty interaction has to do with developmental improvements in strategically controlled SM. Older children and young adults take longer to respond when source discriminations are difficult than when they are easy, whereas my impression is that younger children often respond as quickly under difficult conditions as under easy ones. It may be that older children have better metacognitive insight into when they do versus do not have an adequate basis for making a source attribution and/or are more skilled at deliberately searching for additional source-specifying memory information when needed (Ackerman, 1985; Schacter et al., 1995). Also, preschoolers' memory-test responses seem to be driven largely by the semantic content or gist of the items, rather than recollections of episodic details or verbatim traces (Brainerd and Reyna, 1995). As noted, older children may also place greater reliance on heuristic biases that, while imperfect, often do lead to correct source attributions.

In a series of studies by Poole and Lindsay (1995, 2001, 2002), 3- to 8-year-old children experienced a series of interactive events and subsequently listened to a parent describe some of those events along with nonexperienced events (including an ambiguous instance of touching). Subsequently, when children received an optimal, nonleading interview, many of them reported having experienced events that their parent had described but that they had not really experienced (including a number of reports of the ambiguous touching event). In response to open-ended questions, the oldest children were just as likely as the youngest children to make false reports of suggested events, perhaps reflecting offsetting effects of age-related improvements in ability to remember and talk about the suggestions as well as age-related improvements in the ability to suppress such reports. Late in the interview, children were specifically asked to discriminate between events they remembered experiencing and those that they might merely have heard about. This SM test substantially reduced false reports of suggested events in older children, but had no such effect on younger children.

In Poole and Lindsay's 2002 study, half the children participated in a simple SM-training procedure at the beginning of the interview. In this procedure, the interviewer performed some actions (e.g., wiping off the tape recorder) and talked about performing other actions (e.g., pushing the button to reset the counter on the tape recorder). Immediately thereafter, children were asked whether the experimenter had really performed each action, and they were given explicit corrective feedback (e.g., 'That's right, I really did wipe off the tape recorder; you know that because you saw me do it,' or 'Think hard – Remember when I said that I sometimes push the button to reset the counter on the tape recorder? But you didn't really see me push the button to reset the counter on the tape recorder, did you? No, you didn't, so "No" is the right answer'). This procedure substantially reduced, but did not eliminate, false reports of suggested details in response to direct questions in the main part of the interview for 7- and 8-year-old children; it had no impact on younger children (see also Giles et al., 2002; Bright-Paul et al., 2005; Thierry et al., 2005).

SM is not a single skill that children acquire at a specific age. Rather, SM involves inferences about numerous dimensions of source – remembering who, remembering where, remembering how, remembering when, etc. – and depends upon multiple kinds of mental activities (e.g., perceptual analysis and reflective integration during encoding, revival of memory records, and decision-making processes at test). Thus developmental changes in SM are gradual and situation-specific rather than sudden and global. These considerations also suggest that SM development is correlated with individual differences along a number of dimensions (Lorsbach and Ewing, 1995; Quas et al., 1997; Welch-Ross et al., 1997; Drummey and Newcombe, 2002; Roebers and Schneider, 2005).

### 2.19.3.8 Source Monitoring Performance in Old Age

Henkel et al. (1998) reviewed a wealth of evidence indicating that SM performance generally declines late in life. As with young children, elderly subjects can do well on SM tasks when the sources are highly discriminable, but their performance deteriorates sharply as source similarity increases. Henkel et al. (1998) argued that aging-related SM deficits may be mediated by reductions in the extent to which contextual details are encoded in ways that tightly bind them together with other aspects of an event (see also Lyle et al., 2006). Poorer encoding and integration of features means that older adults are less able to recollect such details later on, leaving them with more vague, abstract memories of experienced events. Such memories are difficult to discriminate from memories of internally generated events.

### 2.19.3.9 The Neuroscience of Source Monitoring

The hippocampus appears to play important roles in episodic memory. Johnson (2006) argued that the hippocampus is particularly important in binding together different aspects or features of an event to create complex, multifaceted memories which, among other things, afford SM attributions. Damage to the hippocampus and surrounding areas has profound debilitating effects on episodic memory (Milner, 2005). Mitchell et al. (2000) used functional magnetic resonance imaging (fMRI) in a short-term memory test in which young and old adults were either required simply to recognize items or to bind together items and locations. They found that younger adults exhibited greater hippocampal activity on binding trials than on item trials, whereas older adults did not (consistent with a selective age effect on performance of SM vs. old/new recognition tests). Johnson (2006) also argued that the prefrontal cortex (PFC) is likely to be involved in noting and reflecting on relationships between features of events, and that such processes, too, play important roles in creating highly source-specific event encodings.

There is also evidence for roles of sensory and motor cortex during encoding in laying the groundwork for subsequent SM performance. In an fMRI study by Gonsalves et al. (2004), for example, subjects saw some items and were asked to imagine seeing others. Activation in visual areas was greater for to-be-imagined items that subjects later erroneously claimed to have seen than for those that they correctly reported imagining, consistent with the idea that vivid and detailed images are more likely to be later mistaken as memories of perceptual events (see Leynes et al., 2006, for a related finding with event-related potential (ERP)).

Earlier, I noted that PFC is thought to be involved in discovering and maintaining attention to relations between different features or aspects of an event in ways that may be important for hippocampal consolidation of complex memories. It is also thought that the PFC plays important SM roles during remembering. Consistent with that claim, Johnson et al. (1997) found greater PFC activity on an SM test than on an old/new test for the same items. Johnson (2006) reviewed a number of ERP and fMRI studies whose findings suggest that the left PFC is particularly important for SM judgments.

## 2.19.4 Related Theoretical Perspectives

### 2.19.4.1 Jacoby's Memory Attribution Approach

Larry Jacoby and his coauthors noted that people sometimes use memory information from specific prior episodes without having the subjective experience of remembering (as in involuntary plagiarism), and that people can have the subjective experience of remembering specific prior episodes that they never in fact experienced (as in various forms of false memories; e.g., Schacter, 2001). Jacoby and coworkers argued that the subjective feeling of remembering arises from an unconscious attribution that is based on the fluency with which an item is processed. Specifically, when cognitive processing is surprisingly fluent one may attribute that fluency to the use of memory, especially if the situation highlights the past (i.e., memory) as a source of influence on current processing (Jacoby and Dallas, 1981; Jacoby and et al., 1989a).

Bruce Whittlesea's SCAPE model can be described as an elaboration of Jacoby et al.'s (1989a) ideas regarding fluency-based attributions to memory. Whittlesea has emphasized that it is unexpected fluency, not fluency *per se*, that leads to memory attributions (a point that was tacit in Jacoby's treatment; e.g., Jacoby and Whitehouse, 1989). Whittlesea and Williams (1998), for example, exposed subjects to words and nonwords and later tested them on a mix of studied and nonstudied words and nonwords. Subjects read each test word aloud before making a recognition judgment to it. Half of the nonwords were regular (e.g., hension), whereas the others were irregular (e.g., stofwus). The key finding was that reading times were fastest on words, but it was the regular nonwords that drew the highest rate of false alarms. Presumably, subjects tended to attribute the fluency with which they read words to their status as words. Regular nonwords may thus have been experienced as surprisingly fluent. It is only when the fluency is discrepant with the person's moment-by-moment impression of how fluent his/her processing should be, and when memory is a plausible source of that fluency, that the person is likely to attribute fluency to memory.

The question of what leads people to attribute thoughts, images, and feelings to memory versus to other sources can be described in terms of the SMF: Thoughts, images, and feelings that come to mind with characteristics typical of memories are likely to be experienced as memories, especially if the person is oriented to the past as a source of current mental events. Similarly, those with the characteristics of perception will tend to be attributed to sensory stimuli (sometimes giving rise to hallucinations; see Johnson, 1988), those with the characteristics of new ideas will be experienced as novel insights, etc. From this perspective, relative fluency is but one cue to source.

### 2.19.4.2 Dual-Process Models of Recognition Memory and the Remember/Know Distinction

Dual-process models of recognition memory hold that items can be correctly recognized as old on either of two independent and qualitatively different bases: (1) Familiarity, a rapid, automatic, undifferentiated feeling of having previously encountered a test item; and (2) recollection, a more deliberative and effortful process of retrieving episodic details regarding the prior encounter with an item (Mandler, 1980; Jacoby, 1991). That contrast is related to the distinction between Remember and Know judgments in the remember/know procedure, in which subjects are asked to indicate whether affirmative recognition judgments are based on episodic recollections of details of encountering the item on the study list or on an undifferentiated feeling of just knowing that the item was on the list.

According to the SMF, processing a test probe sometimes leads to the generation of sufficient source-specifying memory information to enable source identification at a particular grain size, and other times does not (as governed by the principles discussed earlier). The SMF also suggests that certain kinds of memorial information are relatively likely to give rise to a subjective experience of remembering a unique prior episode, whereas others are more likely to give rise to a less-differentiated sense of familiarity. Specifically, source identifications and reports of remembering are likely to arise from access to memories of relatively reflective, elaborative, integrative, distinctive processes. Reports of just knowing, in contrast, are likely to reflect memories of more automatic, data-driven, generic cognitive processes. The recollection/familiarity and remember/know contrasts refer to categorically distinct phenomenological experiences, but from the SMF they are thought to arise from a continuum of memory specificity (Dodson and Johnson, 1996; Gruppuso et al., 1997; Bodner and Lindsay, 2003).

#### 2.19.4.3 Constrained Retrieval

Can you recall an event that occurred when you were in high school that is somehow associated with fire? To generate such a memory, you might in principle first retrieve lots of fire-related memories and then check to see if any of them occurred in high school, but in practice we seem to constrain retrieval such that memories are more likely to come to mind if they are from the to-be-recalled source than if they are from other sources (although of course the constraint is imperfect). Jacoby et al. (2005) proposed that such constrained retrieval plays a central role in enabling individuals to remember material from the appropriate source. They also argued that people can constrain the ways they process recognition test probes so as to facilitate retrieval of memory information from the to-be-recognized source as opposed to memory information from other sources. These provocative new ideas valuably complement the SMF's emphasis on monitoring.

### 2.19.5 Empirical Phenomena Illuminated by the Source Monitoring Framework

The study of memory phenomena that can be described as SM failures or confusions far predates the development of the SMF itself. In this section, I provide brief reviews of a number of such phenomena; for a wider-range review, see Schacter (2001).

#### 2.19.5.1 Verbal Learning Effects

Prior to the development of the SMF, phenomena involving SM had been investigated for many years in the verbal learning tradition. For example, studies of list differentiation assessed subjects' ability to attribute studied words to different study lists (Winograd, 1968; Abra, 1972). This research demonstrated the importance of factors such as semantic similarity and temporal separation of the lists. Such findings informed efforts to understand retroactive and proactive interference effects (Postman, 1975).

#### 2.19.5.2 The Eyewitness Misinformation Effect

Studies of eyewitness memory, and of the effects of suggestive influences on eyewitnesses' reports, have featured prominently if sporadically in the history of psychology (for reviews of early psychological research and speculation on this topic, see Brigham and Grisso, 2003; Goodman, 2006). In the mid-1970s, Beth Loftus and coauthors reported studies that inspired interest in this domain that continues to the date of this writing. Loftus et al. (1978) introduced a three-phase procedure in which subjects first viewed a series of slides depicting an event, then were exposed to verbal information that included misleading suggestions regarding some details in that event, and later were tested on memory for the initially witnessed details. Their key finding was that subjects' answers were often based on the misinformation, rather than on what they had actually witnessed. For example, having seen a slide in which a traffic intersection was marked with a yield sign and then later being exposed to the suggestion that the intersection was marked with a stop sign, subjects quite often reported at test that the intersection had been marked with a stop sign.

Throughout most of the 1980s, debate on this eyewitness misinformation effect focused on the question of whether or not misleading suggestions regarding a witnessed detail impaired witnesses' ability to recall or recognize the witnessed detail (e.g., whether the stop sign suggestion impaired memory for the yield sign). McCloskey and Zaragoza (1985) considerably enlivened that debate with an article providing a cogent logical analysis of the various reasons that suggestions could lower accuracy even if they had zero effect on ability to remember the witnessed details (e.g., compared to control subjects who had never encoded the event detail, misled subjects who also had failed to encode the event detail would be less likely to guess correctly on the test), and six experiments whose results provided no support for any event-detail memory impairment phenomenon (but see Payne et al., 1994; Chandler et al., 2001; Eakin et al., 2003, for evidence that modest memory-impairment effects are obtained under some conditions).

In the late 1980s and throughout the 1990s, attention shifted from this memory-impairment issue to the question of whether or not misled subjects believe that they remembere witnessing details that had in fact merely been suggested to them. This question falls squarely in the purview of the SMF, and the answer (as with any psychological question) is, it depends. As previously mentioned, under some conditions, misinformation effects obtained on a yes/no recognition test (i.e., subjects falsely responding Yes to items that were merely suggested to them) vanish when subjects are given a SM test that orients them toward scrutinizing the sources of their memories (Lindsay and Johsnon, 1989; Zaragoza and Koshmider, 1989). That might be because on the yes/no test subjects sometimes endorse items that they believe they remember from the misinformation (e.g., because they assume the misinformation was accurate). Alternatively, it might be that the SM test leads subjects to use more systematic SM procedures to avoid SM confusions that they would make using more heuristic processes on a yes/no test. Importantly, it has been amply demonstrated that misinformation effects can be obtained on SM tests if the conditions make SM difficult (the sources are highly similar and there is a delay between them and the test, the subjects are young children or elderly adults, etc.; see Lindsay, 1994; Zaragoza and Lane, 1998; Poole and Lindsay, 2001; Mitchell et al., 2003).

Even positive responses on an SM test are not definitive evidence that subjects genuinely believe that they remember witnessing suggested details. If subjects trust the source of the suggestions, they might be tempted to claim that they both remember encountering details in that source and witnessing those details. As a stronger test of the hypothesis that subjects are sometimes genuinely unaware of the source of their memories of suggested details, Lindsay (1991) applied Jacoby's opposition procedure (Jacoby et al., 1989b) in a misinformation paradigm. Subjects witnessed a theft depicted in a series of slides, and were later exposed to a narrative description of the theft that presented misleading suggestions regarding some details and control information about other details. In the difficult condition, the event and narrative were presented in immediate succession, with the test given 2 days later; for subjects in the easy condition, the event was presented on the first day and the narrative was presented 2 days later, immediately followed by the test. This latter condition was easy both in that it should be easy at test to remember the suggestions (which had just been presented minutes before) and it should be easy to differentiate memories of the suggestions from memories of the event (due to the large separation between the two sources). At test, subjects were given cued recall questions along the lines of, 'Under what sort of tool did the handyman hide the stolen calculator in his toolbox?' with half of the questions pertaining to items for which subjects had received misleading suggestions (e.g., hammer in event, wrench in narrative) and others pertaining to items for which no suggestions were given (e.g., see a can of Coca-Cola in the event, read it described as a can of soda in the narrative). Crucially, before taking the test subjects were emphatically told that if they remembered having heard something in the narrative that might be used as an answer to a question on the test they could know for certain that it was a false suggestion, and that they should therefore not report anything they remembered from the narrative. Subjects in the easy condition showed no tendency to report suggested details; given that these subjects were in a good position to remember those details, this indicates that subjects understood and followed the instruction not to report details from the narrative. Subjects in the difficult condition, in contrast, quite often reported suggested details. Significant suggestibility effects under opposition instructions provide powerful evidence that subjects are sometimes genuinely misled about the sources of their memories (see also Holliday and Hayes, 2002; Eakin et al., 2003; Price and Connolly, 2004).

### 2.19.5.3 False Memories Induced by Schemas, Scripts, and Associations

The SMF fits well with earlier research on schema-based memory errors, in which individuals' knowledge and beliefs were shown to distort their memory reports (Bartlett, 1932; Brewer and Treyens, 1981). That is, schemas support the fluent generation of inferences that may have many of the characteristics of memories. As a recent example consistent with this idea, Gerrie et al. (2006) found that subjects who had viewed slides depicting highly scripted events (e.g., making a peanut butter and jelly sandwich) very often falsely recognized script-typical slides that had been omitted from the studied series.

### 2.19.5.4 Other Fluency-Based False Memories

Similar to knowledge and beliefs, other variables that facilitate processing of recognition test probes can increase endorsement rates. For example, Jacoby and Whitehouse (1989) preceded recognition test probes with briefly presented primes that either matched or mismatched the probe. When prime duration was very short, such that subjects were not consciously aware of the presentation of the prime, Yes rates to both old and new probes were higher when preceded by matching primes. Presumably, the brief prime facilitated processing of the test probe and that fluency was attributed to prior exposure on the study list. Of critical importance, when primes were presented for a slightly longer period, so that subjects were consciously aware of them, the data pattern reversed as subjects evidently overattributed the fluency with which they processed test probes to the preceding matching prime. Similarly, Whittlesea (1993) found that a variety of manipulations of the fluency with which test probes were processed affected recognition responses. Lindsay and Kelley (1996) demonstrated analogous effects in cued recall: A manipulation that enhanced the ease with which words popped to mind in response to recall cues increased both accurate and erroneous cued recall reports.

### 2.19.5.5 Veridical and Illusory Recovered Memories of Childhood Sexual Abuse

The 1990s saw a heated controversy regarding cases in which individuals reported that they had recovered long-forgotten histories of childhood sexual abuse. The debate focused on cases in which reports of recovered memories arose in the context of psychotherapy oriented toward fostering memory recovery. Critics of such therapies argued that they were dangerously suggestive and that they sometimes led clients to develop false beliefs or false memories of abuse that never really occurred (Loftus, 1993). Some proponents of trauma-memory-oriented therapies countered that such criticisms were anti-feminist, pro-perpetrator backlash against victims of childhood sexual abuse.

This is a tremendously complex, multifaceted, and emotionally explosive topic, with valid concerns on both sides (Read and Lindsay, 1997). Fortunately, although strenuous contentions still arise in this area (Wade et al., 2007), my perception is that a middle-ground position that acknowledges the likelihood that both essentially accurate and essentially illusory recovered memories occur has come to dominance (Lindsay and Briere, 1997).

In any case, the point for present purposes is that the SMF was of considerable value in understanding how a prolonged, socially influenced, multipronged (albeit well-intentioned) effort to foster the recovery of suspected hidden memories of abuse could, instead, lead individuals to develop false beliefs and memories of abuse (Lindsay and Read, 1994, 2006). There is, for example, some evidence that individuals who report recovered memories are more susceptible to SM confusions on laboratory tasks (McNally et al., 2005) and that they are more prone to forget prior instances of remembering events (Geraerts et al., 2006).

### 2.19.5.6 The Knew-It-All-Along Effect

The knew-it-all-along (KIA) effect, or hindsight bias, is observed when persons report that they possessed knowledge at a previous point of time that they in fact acquired subsequent to that time (Fischhoff, 1975; Wood, 1978; Hasher et al., 1981). Of particular interest here is the memory version of the KIA effect, in which subjects answer a set of questions in phase 1, are then exposed to the correct answers to some of those questions in phase 2, and in phase 3 are asked to re-answer the questions exactly as they did in the first phase. The standard finding in this procedure is that subjects' re-answers to items for which they had been shown the correct answers are often shifted in the direction of the correct answers.

When subjects demonstrate a KIA effect, do they have an (illusory) subjective experience of remembering themselves giving newly learned correct answers on the initial test? Or is their experience merely one of guessing or inferring their prior responses? There is evidence that, under at least some conditions, subjects fail to appreciate the extent to which their re-answers are influenced by the experimental exposure phase in KIA procedures (Begg et al., 1996) and in closely related procedures (e.g., Prentice and Gerrig, 1999; Marsh et al., 2003), but do subjects remember giving correct answers that they did not really give?

To explore this question, Michelle Arnold and I (Arnold and Lindsay, in press) conducted KIA experiments in which subjects were asked to report, for each re-answer, whether they: (1) remembered giving that answer initially, (2) knew they had given that answer without being able to recollect having done so, or (3) felt that they were merely guessing or inferring that they had given that answer. Under standard KIA procedures (passive exposure to the correct answers to trivia questions), when subjects showed a KIA effect they almost always reported guessing or inferring their prior answers. But when the materials were insight problems and the second phase involved providing subjects with sufficient cues to solve the problems, then they quite often subsequently reported false memories of answering questions correctly in the first phase. Presumably in the latter procedure, memories of having been led to figure out a problem in Phase 2 were highly confusable with memories of having spontaneously solved that problem in phase 1.

#### 2.19.5.7 The Forgot-It-All-Along Effect

Schooler et al. (1997) sought out cases in which adults reported having recovered long-forgotten memories of childhood sexual abuse for which there was evidence that the abuse had occurred. They reported two cases in which individuals had apparently told others about the abuse during the period of alleged amnesia. Schooler et al. speculated that these women had recalled the abuse in a qualitatively different way that was accompanied by strong emotions, and that they made an unconscious attribution along the lines of 'I must not have known about this before, lest I wouldn't be so emotionally affected by these recollections.' Schooler et al. termed this hypothetical phenomenon the forgot-it-all-along (FIA) effect, in reference to the aforementioned KIA effect.

Arnold and Lindsay (2002, 2005) developed a laboratory analogy designed to capture some aspects of this hypothesized FIA effect. Subjects were cued to remember items on two different occasions; for half of the items the cues were varied on the two occasions so as to shift the way the subjects thought about the recalled item. On the second test, after each item was recalled, we asked subjects whether they had also recalled that item in the first test. We found that when subjects had recalled the same item on each of the two tests, they were more likely to fail to remember their test-1 recall of the item if they had been cued to think of the item in different ways on the two tests (i.e., a FIA effect). Geraerts et al. (2006, Experiment 2) extended the procedure to memories of autobiographical events and, as mentioned earlier, found larger FIA effects among subjects who reported having recovered repressed memories of childhood sexual abuse than among control subjects.

#### 2.19.5.8 Cryptomnesia

Cryptomnesia, also known as unconscious or inadvertent plagiarism, occurs when an individual mistakes memories of another's ideas as new ideas of his or her own. Brown and Murphy (1989) introduced a three-phase procedure for studying cryptomnesia. In an initial phase, subjects took turns (with one another or with the experimenter or computer) generating items that fit a specified constraint (e.g., names of musical instruments). In the second phase, subjects were asked to recall their own phase-1 contributions. In phase 3, subjects were asked to generate new items not previously generated by them or anyone else in the experiment. Cryptomnesia was often observed in phases 2 and 3, with subjects tending to claim that they recalled themselves generating items that others had in fact generated, and including in their 'new' phase 3 generations items that they or others had generated in phase 1.

As the SMF would lead one to expect, manipulations that increase the similarity between self-generated and other-generated ideas increase rates of cryptomnesia. For example, subjects tested in same-sex pairs show higher rates of cryptomnesia than those tested in different-sex pairs (Macrae et al., 1999), a finding that also emerged in a retrospective self-report survey of everyday cases of cryptomnesia by Defeldre (2005). Marsh et al. (1997) reported converging evidence for the idea that failures in SM processes underlie cryptomnesia. More recently, Stark and Perfect (2006) found that elaborating on another's idea substantially increased subsequent plagiarism, perhaps because the processes performed when elaborating an idea are very similar to and hence highly confusable with those involved in hatching the idea.

#### 2.19.5.9 The Mere Exposure Effect

In a classic paper, Kunst-Wilson and Zajonc (1980) demonstrated that very briefly presented neutral stimuli were subsequently preferred over novel neutral stimuli in two-alternative forced-choice judgments, even though subjects were at chance when explicitly asked to discriminate between previously exposed and new stimuli on the same test pairs. Anecdotal reports (and my own experience) indicate that it is not easy to obtain above-chance preference coupled with at-chance recognition, but that pattern has been reported sufficiently often to compel the conclusion that it is a real albeit delicate phenomenon (Seamon et al., 1983a,b). Both aspects of this effect are interesting. First, it is interesting that influences of prior exposure can be experienced as preference. This is an SM failure of a sort, perhaps reflecting an inherent tendency to prefer stimuli that are easily processed (Winkielman et al., 2006). It is perhaps noteworthy that to the best of my knowledge, the effect on preference in the absence of recognition has only been reported with stimuli that afford little in the way of strong preferences (e.g., random polygons). It is also intriguing that subjects at chance on recognition have been shown to select previously exposed items at above-chance levels on certain other kinds of judgments (e.g., brightness or darkness judgments in Mandler et al., 1987; see Seamon et al., 1998, for evidence that it is easier to obtain the dissociation pattern with affective judgments than other sorts of judgments).

Arguably more interesting than the above-chance performance on preference judgments is that, having memories sufficient to generate this preference effect, subjects nonetheless respond on the recognition test as though they had no such memories. Whittlesea and Price (2001) offered arguments and evidence to the effect that this dissociation arises because subjects tend to make preference judgments in a nonanalytic, holistic manner, whereas they tend to make recognition judgments in a more analytic, feature-based manner. Presumably, the latter orientation toward test stimuli reduces the extent to which subjects cue revival of the weak and poorly bound memory records of the prior exposure. This may also account for the evidence of Seamon et al. (1998), mentioned previously, that various judgment tasks are differentially sensitive under conditions that lead to chance-level recognition.

#### 2.19.5.10 Déjà Vu

Most people report that they have had the uncanny experience of being in what they know to be a novel situation and yet feeling that they have previously been in that situation. If the mere exposure effect is tough to get in the lab, déjà vu is nigh unto impossible, so the latter effect has been studied with self-report measures. Brown (2004) summarized that research and offered three accounts of déjà vu: (1) a decoupling of streams of perceptual processing that normally progress in synchrony, such that one stream runs faster than the other with the later stream, then cuing memories of the (milliseconds old) faster stream; (2) a momentary lapse of attention, during which perceptual processes carry on automatically, with memories of those (poorly bound) perceptual processes being cued when attention returns to the ongoing situation; and (3) partial revival of memories of some similar past situation, giving rise to a strong feeling of familiarity without providing sufficient source-specifying information to enable the person to attribute that familiarity to its correct source. The last of these accounts is most amenable with a memory SM perspective, but as discussed in the next section, all three are in keeping with a broader approach to SM.

## 2.19.6 Challenges and Future Directions

### 2.19.6.1 Multidimensional Source Monitoring

Most studies motivated by the SMF have explored rememberers' ability to discriminate between memories from two sources (e.g., two external sources or an external source versus an internal source such as a spontaneous inference or a directed image), typically using forced-choice tests. In everyday life, SM is much less constrained. If, for example, you try to remember how you got the idea that polar bear hair is translucent and hollow, the range of potential sources is very wide. A number of recent studies have tested SM across two pairs of nested sources (e.g., identifying which of four individuals – two women and two men – had said particular words; Dodson et al., 1998). Some studies have involved simultaneous explorations of two different dimensions of source manipulated orthogonally (e.g., font size and location; Marsh et al., 2004; Starns and Hicks, 2005). I suspect that much more can be done to explore SM in situations in which the range of potential sources is broad.

### 2.19.6.2 Interpersonal Source Monitoring

In the course of conversation, auditors sometimes make inferences regarding the sources of their interlocutor's memory reports. You may, for example, have listened to someone relating an anecdote and thought to yourself, 'He's probably making that part up,' or 'I bet she's exaggerating a bit,' or 'I bet he got that from the *National Enquirer*.' The bases for such inferences are likely numerous and complex, particularly in cases in which the auditor has extensive prior experience with the storyteller or has independent knowledge of the content of the tale. Such inferences have as much to do with social and personality psychology as with cognition, but nonetheless the SMF may inspire hypotheses about at least some of the processes involved in making inferences about the accuracy and source of another person's verbal reports.

Even when listening to an unfamiliar person describing a novel event, auditors may make inferences about the accuracy and reliability of those reports. This is especially so when conditions foster concerns about lying (as in police investigations), and there is an extensive and fascinating literature on deception detection (Granhag and Vrij, 2005). Sporer (2004) has developed a deception-detection scale based in part on the SMF, and this approach appears to have substantial potential. Relatedly, jurors weigh the testimony of witnesses, evidently driven largely by the witnesses' apparent confidence (e.g., Brewer and Burke, 2002; Tetterton and Warren, 2005).

It is also interesting to consider interpersonal SM in situations in which lying is not at issue but in which storytellers might nonetheless be mistaken. Schooler et al. (1986) exposed subjects to misleading suggestions regarding a witnessed event, had them write descriptions of the event, and gave those descriptions to new subjects for evaluation; these evaluations were slightly but significantly above chance (see also Johnson and Suengas, 1989). Johnson et al. (1998) found that the more details an account contained, the more believable naive judges found that account to be. Lindsay et al. (2000) found that undergraduates role-playing as police officers were above chance at discriminating between accurate and inaccurate truthful witnesses, but that they did so less well than witnesses' own self-ratings of confidence (see also Dahl et al., 2006). Here again the SMF is a source of hypotheses as to how perceivers make such judgments and how their accuracy might be improved.

### 2.19.6.3 Falsifiability

The SMF has a great many degrees of freedom. For one thing, memory records are described as multifaceted, imperfectly bound constellations of numerous aspects or features, from low-level perceptual primitives to conceptual reflections. Thus, for example, two sources might be highly similar along some dimensions and quite distinct along others (e.g., Marisa and Jim might both have Spanish accents but very different pitches, whereas Marisa and Elke might have similar pitches but different accents). How do multiple dimensions of similarity interact? As another example, compared to generating an image of an item once, generating it several times may increase both (1) records of cognitive operations associated with generating an image of that item (which could be taken as evidence that the item was generated) and (2) the fluency and vividness with which the latter images were generated (which could be taken as evidence that the item was perceived). Without a theory to specify which aspects will be more or less accessible and more or less heavily weighted in a particular situation, it is not always obvious which conditions will lead to more or fewer SM failures.

Moreover, SM performance is said to depend not only on the characteristics of memory records but also on the rememberer's expectations, biases, stereotypes, current orientation, and goals. Variations along these higher-level dimensions can interact with variations in the characteristics of memory records. As an example, consider an eyewitness misinformation study by Bonto and Payne (1991), in which some subjects were exposed to the witnessed event and the postevent information in the same context, whereas others were exposed to the two sources in a different context. The SMF would predict that source discriminations would be more difficult in the same-context condition than in the different-context condition, but Bonto and Payne found equivalent (and substantial) influences of misinformation in both conditions. One possible account has to do with the fact that Bonto and Payne's procedure likely encouraged subjects to rely on memories from both sources. There was no warning about misinformation, so subjects may have assumed that the postevent information was a legitimate and reliable source of answers to test questions and hence not been concerned about discriminating memories from the two sources.

Some of the most clever SM research in recent years has come out of the labs of Rich Marsh and his coauthors, including several studies that further illustrate the difficulty of using the SMF to make specific predictions. In a study by Marsh et al. (2002), for example, subjects were presented with compound words (e.g., deadbolt, neckline) in two sources and were later tested on either a yes/no recognition test or on a SM test. Of central interest was the rate of falsely claiming to have studied conjunctions (e.g., deadline). One might expect that the SM test would lead subjects to scrutinize their recollections more carefully before responding and thereby lower the rate of such errors. Instead, Marsh et al. found that when the two sources were sharply dissimilar and when the 'parents' of a conjunction had both been presented in the same source, then subjects tested with the SM test were more likely to make conjunction errors than were subjects tested with the recognition test (for related results, see Hicks and Marsh, 2001). Marsh, Hicks, and their colleagues have discussed these and similar results in terms consistent with the SMF, but the point for present purposes is that the framework does not always provide a clear and firm framework for predicting behavior in complex situations.

In many well-controlled and simple experiments, the SMF is falsifiable, but in more complex, less controlled situations it is often possible to fashion accounts consistent with the SMF for a variety of different empirical outcomes. Some theorists (e.g., Reyna and Lloyd, 1997) have strongly criticized the SMF for this limited falsifiability. This may partly be a matter of taste, with some theorists putting a premium on falsifiability and others esteeming the extent to which a theory serves to organize and inspire nuanced hypotheses regarding a wide range of phenomena. Of course, in the long run, proponents of the SMF hope to more precisely specify the interactions among the numerous variables involved in attributing mental events to particular sources.

## 2.19.7 Conclusion

Some theories describe remembering as a matter of using the episodic memory system, knowing as a matter of using the semantic memory system, skilled performance as a matter of using the procedural memory system, etc. Indubitably there are functional brain systems specialized for the sorts of cognitive processes that typically support remembering, knowing, doing, etc. But just as surely those brain systems do not operate in isolation from one another, and the thoughts, images, and feelings to which they give rise are products of multiple subsystems interacting. Because the implications of mental contents vary greatly as a function of their sources (e.g., remembering that one previously encountered a tiger near this water hole is more consequential than remembering that one previously dreamed of such an encounter and less consequential than currently sighting a tiger), we routinely monitor the sources of our thoughts, images, and feelings. The SMF provides a productive way of thinking about the processes by which such attributions are made.

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## References

Abra JC (1972) List differentiation and forgetting. In: Duncan CP, Sechrest L, and Melton AW (eds.) *Human Memory: Festschrift for Benton J. Underwood*, pp. 25–57. New York: Appleton-Century-Crofts.
Ackerman BP (1985) Children's use of context and category cues to retrieve episodic information from memory. *J. Exp. Child Psychol.* 40: 420–438.
Anderson JR and Bower GH (1972) Recognition and retrieval processes in free recall. *Psychol. Rev.* 79: 97–123.
Anderson JR and Bower GH (1974) Interference in memory for multiple contexts. *Mem. Cognit.* 2: 509–514.
Anderson JR and Matessa M (1997) A production system theory of serial memory. *Psychol. Rev.* 104: 728–748.
Arnold MM and Lindsay DS (2002) Remembering remembering. *J. Exp. Psychol. Learn* 28: 521–529.
Arnold MM and Lindsay DS (2005) Remembrance of remembrance past. *Memory* 13: 533–549.
Arnold MM and Lindsay DS (in press) I remember/know/guess that I knew-it-all-along!: Subjective experience versus objective measures of the knew-it-all-along effect *Mem. Cognit.*
Banks WP (2000) Recognition and source memory as multivariate decision processes. *Psychol. Sci.* 11(4): 267–273.
Bartlett FC (1932) *Remembering: A Study in Experimental and Social Psychology*. New York: Macmillan.
Batchelder WH and Riefer DM (1990) Multinomial processing models of source monitoring. *Psychol. Rev.* 97: 548–564.
Batchelder WH, Reifer DM, and Hu X (1994) Measuring memory factors in source monitoring: Reply to Kinchla. *Psychol. Rev.* 101: 172–176.
Bayen UJ and Murnane K (1996) Aging and the use of perceptual and temporal information in source memory tasks. *Psychol. Aging* 11: 293–303.
Begg I, Robertson R, Gruppuso V, Anas A, and Needham D (1996) The illusory-knowledge effect. *J. Mem. Lang.* 35: 410–433.
Berntsen D and Rubin DC (2004) Cultural life scripts structure recall from autobiographical memory. *Mem. Cognit.* 32: 427–442.
Bink ML, Marsh RL, and Hicks JL (1999) An alternative conceptualization to memory 'strength' in reality monitoring. *J. Exp. Psychol. Learn.* 25: 804–809.
Bodner GE and Lindsay DS (2003) Remembering and knowing in context. *J. Mem. Lang.* 48: 563–580.
Bonto MA and Payne DG (1991) Role of environmental context in eyewitness memory. *Am. J. Psychol.* 104: 117–134.
Brainerd CJ and Reyna VF (1990) Gist is the grist: Fuzzy-trace theory and the new intuitionism. *Dev. Rev.* 10: 3–47.
Brainerd CJ and Reyna VF (1995) Autosuggestibility in memory development. *Cogn. Psychol.* 28: 65–101.
Brewer N and Burke A (2002) Effects of testimonial inconsistencies and eyewitness confidence on mock-juror judgments. *Law Hum. Behav.* 26: 353–364.
Brewer WF and Treyens JC (1981) Role of schemata in memory for places. *Cogn. Psychol.* 13: 207–230.

Brigham JC and Grisso J (2003) Forensic psychology. In: Freedheim DK (ed.) *Handbook of Psychology: History of Psychology,* vol. 1, pp. 391–411. New York: Wiley.
Bright-Paul A, Jarrold C, and Wright DB (2005) Age-appropriate cues facilitate source-monitoring and reduce suggestibility in 3- to 7-year-olds. *Cogn. Dev.* 20: 1–18.
Brown AS (2004) The déjà vu illusion. *Curr. Dir. Psychol. Sci.* 13: 256–259.
Brown AS and Murphy DR (1989) Cryptomnesia: Delineating inadvertent plagiarism. *J. Exp. Psychol. Learn.* 15: 432–442.
Brown NR, Shevell SK, and Rips LJ (1986) Public memories and their personal context. In: Rubin DC (ed.) *Autobiographical Memory*, pp. 137–158. Cambridge: Cambridge University Press.
Brown R and Kulik J (1977) Flashbulb memories. *Cognition* 5: 73–99.
Burt CD (1993) The effect of actual event duration and event memory on the reconstruction of duration information. *Appl. Cogn. Psychol.* 7: 63–73.
Castel AD and Craik FIM (2003) The effects of aging and divided attention on memory for item and associative information. *Psychol. Aging* 18: 873–885.
Chandler CC, Gargano GJ, and Holt BC (2001) Witnessing postevents does not change memory traces, but can affect their retrieval. *Appl. Cogn. Psychol.* 15(1): 3–22.
Connolly DA and Lindsay DS (2001) The influence of suggestions on children's reports of a unique experience versus an instance of a repeated experience. *Appl. Cogn. Psychol.* 15: 205–223.
Dahl LC, Lindsay DS, and Brimacombe CA (2006) Investigating investigators: Examining witnesses' influence on investigators. *Law Hum. Behav.* 30: 707–732.
Defeldre A (2005) Inadvertent plagiarism in everyday life. *Appl. Cogn. Psychol.* 19: 1033–1040.
Dodson CS and Hege ACG (2005) Speeded retrieval abolishes the false-memory suppression effect: Evidence for the distinctiveness heuristic. *Psychon. Bull. Rev.* 12: 726–731.
Dodson CS and Johnson MK (1996) Some problems with the process-dissociation approach to memory. *J. Exp. Psychol. Gen.* 125: 181–194.
Dodson CS and Schacter DL (2002) When false recognition meets metacognition: The distinctiveness heuristic. *J. Mem. Lang.* 46: 782–803.
Dodson CS, Holland PW, and Shimamura AP (1998) On the recollection of specific- and partial-source information. *J. Exp. Psychol. Learn.* 24: 1121–1136.
Drummey AB and Newcombe NS (2002) Developmental changes in source memory. *Dev. Sci.* 5: 502–513.
Eakin DK, Schreiber TA, and Sergent-Marshall S (2003) Misinformation effects in eyewitness memory: The presence and absence of memory impairment as a function of warning and misinformation accessibility. *J. Exp. Psychol. Learn. Mem. Cogn.* 29(5): 813–825.
Echterhoff G, Higgins ET, Kopietz R and Groll S (in press) How communication goals determine when audience tuning biases memory. *J. Exp. Psychol. Gen.*
Echterhoff G, Hirst W, and Hussy W (2005) How eyewitnesses resist misinformation: Social postwarnings and the monitoring of memory characteristics. *Mem. Cognit.* 33: 770–782.
Finke RA, Johnson MK, and Shyi GC (1988) Memory confusions for real and imagined completions of symmetrical visual patterns. *Mem. Cognit.* 16: 133–137.
Fischhoff B (1975) Hindsight is not equal to foresight: The effect of outcome knowledge on judgment under uncertainty. *J. Exp. Psychol. Hum. Percept. Perform.* 1: 288–299.
Foley MA and Johnson MK (1985) Confusions between memories for performed and imaginary actions: A developmental comparison. *Child Dev.* 56: 1145–1155.
Foley MA and Ratner HH (1998) Children's recoding memory for collaboration: A way of learning from others. *Cogn. Dev.* 13: 91–108.
Foley MA, Johnson MK, and Raye CL (1983) Age-related changes in confusion between memories for thoughts and memories for speech. *Child Dev.* 54: 51–60.
Foley MA, Santini C, and Soposakis M (1989) Discriminating between memories: Evidence for children's spontaneous elaborations. *J. Exp. Child Psychol.* 48: 146–169.
Foley MA, Ratner HH, and House AT (2002) Anticipation and source-monitoring errors: Children's memory for collaborative activities. *J. Cogn. Dev.* 3: 385–414.
Friedman WJ (1987) A follow-up to 'Scale effects in memory for the time of events': The earthquake study. *Mem. Cognit.* 15: 518–520.
Friedman WJ (2004) Time in autobiographical memory. *Soc. Cogn.* 22: 591–605.
Friedman WJ and Lyon TD (2005) Development of temporal-reconstructive abilities. *Child Dev.* 76: 1202–1216.
Frost P, Ingraham M, and Wilson B (2002) Why misinformation is more likely to be recognized over time: A source monitoring account. *Memory* 10: 179–185.
Gallo DA and Roediger HL III (2003) The effects of associations and aging on illusory recollection. *Mem. Cognit.* 31: 1036–1044.
Gallo DA, McDermott KB, Percer JM, and Roediger HL III (2001) Modality effects in false recall and false recognition. *J. Exp. Psychol. Learn.* 27: 339–353.
Geraerts E, Arnold MM, Lindsay DS, Merckelbach H, Jelicic M, and Hauer B (2006) Forgetting of prior remembering in persons reporting recovered memories of childhood sexual abuse. *Psychol. Sci.* 17: 1002–1008.
Gerrie MP, Belcher LE, and Garry M (2006) 'Mind the gap': False memories for missing aspects of an event. *Appl. Cogn. Psychol.* 20: 689–696.
Giles JW, Gopnik A, and Heyman GD (2002) Source monitoring reduces the suggestibility of preschool children. *Psychol. Sci.* 13: 288–291.
Glanzer M, Hilford A, and Kim K (2004) Six regularities of source recognition. *J. Exp. Psychol. Learn.* 30: 1176–1195.
Gonsalves B, Reber PJ, Gitelman DR, Parrish TB, Mesulam MM, and Paller KA (2004) Neural evidence that vivid imagining can lead to false remembering. *Psychol. Sci.* 15: 655–660.
Goodman GS (2006) Children's eyewitness memory: A modern history and contemporary commentary. *J. Soc. Issues* 62: 811–832.
Granhag P-A and Vrij A (2005) Deception detection. In: Brewer N and Williams KD (eds.) *Psychology and Law: An Empirical Perspective*, pp. 43–92. New York: Guilford Press.
Gruppuso V, Lindsay DS, and Kelley CM (1997) The process-dissociation procedure and similarity: Defining and estimating recollection and familiarity in recognition memory. *J. Exp. Psychol. Learn.* 23: 259–278.
Hasher L, Attig MS, and Alba JW (1981) I knew it all along – or, did I? *J. Verb. Learn. Verb. Behav.* 20: 86–96.
Hashtroudi S, Johnson MK, and Chrosniak LD (1989) Aging and source monitoring. *Psychol. Aging* 4: 106–112.
Henkel LA, Johnson MK, and De Leonardis DM (1998) Aging and source monitoring: Cognitive processes and neuropsychological correlates. *J. Exp. Psychol. Gen.* 127: 251–268.
Hicks JL and Marsh RL (2001) False recognition occurs more frequently during source identification than during old-new recognition. *J. Exp. Psychol. Learn.* 27: 375–383.
Higgins ET and Rholes WS (1978) 'Saying is believing': Effects of message modification on memory and liking for the person described. *J. Exp. Soc. Psychol.* 14: 363–378.

Hoffman HG (1997) Role of memory strength in reality monitoring decisions: Evidence from source attribution biases. *J. Exp. Psychol. Learn.* 23: 371–383.

Holliday RE and Hayes BK (2002) Automatic and international processes in children's recognition memory: The reversed misinformation effect. *Appl. Cogn. Psychol.* 16(1): 1–16.

Jacoby LL (1991) A process dissociation framework: Separating automatic from intentional uses of memory. *J. Mem. Lang.* 30: 513–541.

Jacoby LL and Dallas M (1981) On the relationship between autobiographical memory and perceptual learning. *J. Exp. Psychol. Gen.* 110: 306–340.

Jacoby LL and Whitehouse K (1989) An illusion of memory: False recognition influenced by unconscious perception. *J. Exp. Psychol. Gen.* 118: 126–135.

Jacoby LL, Kelley CM, and Dywan J (1989a) Memory attributions. In: Roediger HL III and Craik FIM (eds.) *Varieties of Memory and Consciousness: Essays in Honor of Endel Tulving*, pp. 391–422. Hillsdale, NJ: Erlbaum.

Jacoby LL, Woloshyn V, and Kelley C (1989b) Becoming famous without being recognized: Unconscious influences of memory produced by dividing attention. *J. Exp. Psychol. Gen.* 118: 115–125.

Jacoby LL, Yonelinas AP, and Jennings JM (1997) The relation between conscious and unconscious (automatic) influences: A declaration of independence. In: Cohen JD and Schooler JW (eds.) *Scientific Approaches to Consciousness*, pp. 13–47. Hillsdale, NJ: Erlbaum.

Jacoby LL, Shimizu Y, Daniels KA, and Rhodes MG (2005) Modes of cognitive control in recognition and source memory: Depth of retrieval. *Psychon. Bull. Rev.* 12: 852–857.

Jennings JM and Jacoby LL (1997) An opposition procedure for detecting age-related deficits in recollection: Telling effects of repetition. *Psychol. Aging* 12: 352–361.

Johnson MK (1985) The origins of memories. In: Kendall PC (ed.) *Advances in Cognitive-Behavioral Research and Therapy*, pp. 1–27. New York: Academic Press.

Johnson MK (1988) Discriminating the origin of information. In: Oltmanns TF and Maher BA (eds.) *Delusional Beliefs*, pp. 34–65. New York: Wiley.

Johnson MK (1994) Binding complex memories: The role of reactivation and the hippocampus. In: Schacter DL and Tulving E (eds.) *Memory Systems*, pp. 311–350. Cambridge, MA: MIT Press.

Johnson MK (1997) Identifying the origin of mental experience. In: Myslobodsky MS (ed.) *The Mythomanias: The Nature of Deception and Self-Deception*, pp. 133–180. Hillsdale, NJ: Erlbaum.

Johnson MK (2005) The relation between source memory and episodic memory: Comment on Siedlecki et al. (2005). *Psychol. Aging* 20: 529–531.

Johnson MK and Raye CL (1981) Reality monitoring. *Psychol. Rev.* 88: 67–85.

Johnson MK and Suengas AG (1989) Reality monitoring judgments of other people's memories. *Bull. Psychon. Soc.* 27: 107–110.

Johnson MK (2006) Memory and reality. *Am. Psychol.* 61: 760–771.

Johnson MK, Raye CL, Foley HJ, and Foley MA (1981) Cognitive operations and decision bias in reality monitoring. *Am. J. Psychol.* 94: 37–64.

Johnson MK, Foley MA, and Leach K (1988a) The consequences for memory of imagining in another person's voice. *Mem. Cognit.* 16: 337–342.

Johnson MK, Foley MA, Suengas AG, and Raye CL (1988b) Phenomenal characteristics of memories for perceived and imagined autobiographical events. *J. Exp. Psychol. Gen.* 117: 371–376.

Johnson MK, Hashtroudi S, and Lindsay DS (1993) Source monitoring. *Psychol. Bull.* 114: 3–28.

Johnson MK, Kounios J, and Reeder JA (1994) Time-course studies of reality monitoring and recognition. *J. Exp. Psychol. Learn.* 20: 1409–1419.

Johnson MK, Nolde SF, and De Leonardis DM (1996) Emotional focus and source monitoring. *J. Mem. Lang.* 35: 135–156.

Johnson MK, Nolde SF, Mather M, Kounios J, Schacter DL, and Curran T (1997) The similarity of brain activity associated with true and false recognition memory depends on test format. *Psychol. Sci.* 8: 250–257.

Johnson MK, Bush JG, and Mitchell KJ (1998) Interpersonal reality monitoring: Judging the sources of other people's memories. *Soc. Cogn.* 16: 199–224.

Johnson MK, Raye CL, and Mitchell KJ (2005) Using fMRI to investigate a component process of reflection: Prefrontal correlates of refreshing a just-activated representation. *Cogn. Affect. Behav. Neurosci.* 5: 339–361.

Jones TC (2006) Editing (out) generated study words in a recognition exclusion task: Effects of response signal delay and generation procedure. *Memory* 14: 712–729.

Kolers PA and Roediger HL (1984) Procedures of mind. *J. Verb. Learn. Verb. Behav.* 23: 425–449.

Kunst-Wilson WR and Zajonc RB (1980) Affective discrimination of stimuli that cannot be recognized. *Science* 207: 557–558.

Lampinen JM, Neuschatz JS, and Payne DG (1999) Source attributions and false memories: A test of the demand characteristics account. *Psychon. Bull. Rev.* 6: 130–135.

Lane SM (2006) Dividing attention during a witnessed event increases eyewitness suggestibility. *Appl. Cogn. Psychol.* 20: 199–212.

Lane SM, Mather M, Villa D, and Morita SK (2001) How events are reviewed matters: Effects of varied focus on eyewitness suggestibility. *Mem Cognit.* 29: 940–947.

Lee PJ and Brown NR (2004) The role of guessing and boundaries on date estimation biases. *Psychon. Bull. Rev.* 11: 748–754.

Leynes PA, Grey JA, and Crawford JT (2006) Event-related potential (ERP) evidence for sensory-based action memories. *Int. J. Psychophysiol.* 62: 193–202.

Lindsay DS (1991) CHARMed, but not convinced: Comment on Metcalfe (1990). *J. Exp. Psychol.Gen.* 120: 101–105.

Lindsay DS (1994) Memory source monitoring and eyewitness testimony. In: Ross DF, Read JD, and Toglia MP (eds.) *Adult Eyewitness Testimony: Current Trends and Developments*, pp. 27–55. Cambridge: Cambridge University Press.

Lindsay DS (2002) Children's source monitoring. In: Westcott HL, Davies G, and Bull RHC (eds.) *Children's Testimony: Psychological Research and Forensic Practice*, pp. 83–98. New York: Wiley.

Lindsay DS and Briere J (1997) The controversy regarding recovered memories of childhood sexual abuse: Pitfalls, bridges and future directions. *J. Interpers. Violence* 12: 631–647.

Lindsay DS and Kelley CM (1996) Creating illusions of familiarity in a cued recall remember/know paradigm. *J. Mem. Lang.* 35: 197–211.

Lindsay DS and Johnson MK (1989) The eyewitness suggestibility effect and memory for source. *Mem. Cognit.* 17: 349–358.

Lindsay DS and Johnson MK (1991) Recognition memory and source monitoring. *Bull. Psychon. Soc.* 29: 203–205.

Lindsay DS and Read JD (1994) Psychotherapy and memories of childhood sexual abuse: A cognitive perspective. *Appl. Cogn. Psychol.* 8: 281–338.

Lindsay DS and Read JD (2006) Adults' memories of long-past events. In: Nilsson G-G and Ohta N (eds.) *Memory and Society: Psychological Perspectives*, pp. 51–72. Hove, UK: Psychology Press.

Lindsay DS, Johnson MK, and Kwon P (1991) Developmental changes in memory source monitoring. *J. Exp. Child Psychol.* 52: 297–318.

Lindsay DS, Nilsen E, and Read JD (2000) Witnessing-condition heterogeneity and witnesses' versus investigators' confidence in the accuracy of witnesses' identification decisions. *Law Hum. Behav.* 24: 685–697.

Loftus EF (1993) The reality of repressed memories. *Am. Psychol.* 48: 518–537.

Loftus EF, Miller DG, and Burns HJ (1978) Semantic integration of verbal information into a visual memory. *J. Exp. Psychol. Hum. Learn. Mem.* 4: 19–31.

Lorsbach TC and Ewing RH (1995) Source monitoring in children with learning disabilities. *Int. J. Disabil. Dev. Educ.* 42: 241–257.

Lyle KB, Bloise SM, and Johnson MK (2006) Age-related binding deficits and the content of false memories. *Psychol. Aging* 21: 86–95.

Macrae CN, Bodenhausen G, and Calvini G (1999) Contexts of cryptomnesia: May the source be with you. *Soc. Cogn.* 17: 273–297.

Mandler G (1980) Recognizing: The judgment of previous occurrence. *Psychol. Rev.* 87: 252–271.

Mandler G, Nakamura Y, and VanZandt BJ (1987) Nonspecific effects of exposure on stimuli that cannot be recognized. *J. Exp. Psychol. Learn.* 13: 646–648.

Marsh EJ and Tversky B (2004) Spinning the stories of our lives. *Appl. Cogn. Psychol.* 18: 491–503.

Marsh RL, Landau JD, and Hicks JL (1997) Contributions of inadequate source monitoring to unconscious plagiarism during idea generation. *J. Exp. Psychol. Learn.* 23: 886–897.

Marsh RL, Hicks JL, and Davis TT (2002) Source monitoring does not alleviate (and may exacerbate) the occurrence of memory conjunction errors. *J. Mem. Lang.* 47: 315–326.

Marsh E, Meade M, and Roediger HL III (2003) Learning facts from fiction. *J. Mem. Lang.* 49: 519–536.

Marsh RL, Hicks JL, and Cook GI (2004) Focused attention on one contextual attribute does not reduce source memory for a different attribute. *Memory* 12: 183–192.

Marsh RL, Cook GI, and Hicks JL (2006) Gender and orientation stereotypes bias source-monitoring attributions. *Memory* 14: 148–160.

Mather M, Henkel LA, and Johnson MK (1997) Evaluating characteristics of false memories: Remember/know judgments and memory characteristics questionnaire compared. *Mem. Cognit.* 25: 826–837.

Mather M, Johnson MK, and De Leonardis DM (1999) Stereotype reliance in source monitoring: Age differences and neuropsychological test correlates. *Cogn. Neuropsychol.* 16: 437–458.

Mather M, Mitchell KJ, Raye CL, Novak DL, Greene EJ, and Johnson MK (2006) Emotional arousal can impair feature binding in working memory. *J. Cogn. Neurosci.* 18: 614–625.

McClelland JL and Rumelhart DE (1985) Distributed memory and the representation of general and specific information. *J. Exp. Psychol. Gen.* 114: 159–188.

McClelland JL, Rumelhart DE, and Hinton GE (2003) Parallel distributed processing: Explorations in the microstructure of cognition. In: Munger MP (ed.) *The History of Psychology: Fundamental Questions*, pp. 478–492. Oxford: Oxford University Press.

McCloskey M and Zaragoza M (1985) Misleading postevent information and memory for events: Arguments and evidence against memory impairment hypotheses. *J. Exp. Psychol. Gen.* 114: 1–16.

McElree B, Dolan PO, and Jacoby LL (1999) Isolating the contributions of familiarity and source information to item recognition: A time course analysis. *J. Exp. Psychol. Learn.* 25: 563–582.

McIntyre JS and Craik FI (1987) Age differences in memory for item and source information. *Can. J. Psychol.* 41: 175–192.

McNally RJ, Clancy SA, Barrett HM, and Parker HA (2005) Reality monitoring in adults reporting repressed, recovered, or continuous memories of childhood sexual abuse. *J. Abnorm. Psychol.* 114: 147–152.

Meiser T (2005) A hierarchy of multinomial models for multidimensional source monitoring. *Methodol. Eur. J. Res. Methods Behav. Soc. Sci.* 1: 2–17.

Milner B (2005) The medial temporal-lobe amnesic syndrome. *Psychiatr. Clin. N. Am.* 28: 599–611.

Mitchell KJ, Livosky M, and Mather M (1998) The weapon focus effect revisited: The role of novelty. *Legal Criminol. Psychol.* 3: 287–303.

Mitchell KJ, Johnson MK, Raye CL, and D'Esposito M (2000) fMRI evidence of age-related hippocampal dysfunction in feature binding in working memory. *Brain Res. Cogn. Brain Res.* 10: 197–206.

Morris CD, Bransford JD, and Franks JJ (1977) Levels of processing versus transfer appropriate processing. *J. Verb. Learn. Verb. Behav.* 16: 519–533.

Murnane K, Phelps MP, and Malmberg K (1999) Context-dependent recognition memory: The ICE theory. *J. Exp. Psychol. Gen.* 128: 403–415.

Neisser U (1981) John Dean's memory: A case study. *Cognition* 9: 1–22.

Parks CM and Yonelinas AP (2007) Moving beyond pure signal-detection models: Comment on Wixted (2007). *Psychol. Rev.* 114: 188–201.

Payne DG and Blackwell JM (1998) Truth in memory: Caveat emptor. In: Lynn SJ and McConkey KM (eds.) *Truth in Memory*, pp. 32–61. New York: Guilford Press.

Payne DG, Toglia MP, and Anastasi JS (1994) Recognition performance level and the magnitude of the misinformation effect in eyewitness memory. *Psychon. Bull. Rev.* 1(3): 376–382.

Poole DA and Lindsay DS (1995) Interviewing preschoolers: Effects of nonsuggestive techniques, parental coaching, and leading questions on reports of nonexperienced events. *J. Exp. Child Psychol.* 60: 129–154.

Poole DA and Lindsay DS (2001) Children's eyewitness reports after exposure to misinformation from parents. *J. Exp. Psychol. Appl.* 7: 27–50.

Poole DA and Lindsay DS (2002) Reducing child witnesses' false reports of misinformation from parents. *J. Exp. Child Psychol.* 81: 117–140.

Postman L (1975) Tests of the generality of the principle of encoding specificity. *Mem. Cognit.* 3: 663–672.

Prentice D and Gerrig R (1999) *Exploring the Boundary Between Fiction and Reality*. New York: Guilford Press.

Price HL and Connolly DA (2004) Event frequency and children's suggestibility: A study of cued recall responses. *Appl. Cogn. Psychol.* 18(7): 809–821.

Qin J, Raye CL, and Johnson MK (2001) Source ROCs are (typically) curvilinear: Comment on Yonelinas (1999). *J. Exp. Psychol. Learn.* 27: 1110–1115.

Quas JA, Qin J, Schaaf J, and Goodman GS (1997) Individual differences in children's and adults' suggestibility and false event memory. *Learn. Ind. Differ.* 9: 359–390.

Read JD and Lindsay DS (1997) *Recollections of Trauma: Scientific Evidence and Clinical Practice*. New York: Plenum Press.

Reyna VF and Lloyd F (1997) Theories of false memory in children and adults. *Learn. Ind. Differ.* 9: 95–123.

Roebers CM and Schneider W (2005) Individual differences in young children's suggestibility: Relations to event memory, language abilities, working memory, and executive functioning. *Cogn. Dev.* 20: 427–447.

Roediger HL, McDermott KB, Pisoni DB, and Gallo DA (2004) Illusory recollection of voices. *Memory* 12: 586–602.
Schacter DL (2001) *The Seven Sins of Memory: How the Mind Forgets and Remembers*. New York: Houghton Mifflin.
Schacter DL, Harbluk JL, and McLachlan DR (1984) Retrieval without recollection: An experimental analysis of source amnesia. *J. Verb. Learn. Verb. Behav.* 23: 593–611.
Schacter DL, Kagan J, and Leichtman MD (1995) True and false memories in children and adults: A cognitive neuroscience perspective. *Psychol. Public Pol. Law* 1: 411–428.
Schooler JS, Gerhard D, and Loftus EF (1986) Qualities of the unreal. *J. Exp. Psychol. Learn.* 12: 171–181.
Schooler JS, Ambadar Z, and Bendikson M (1997) A cognitive corroborative case study approach for investigating discovered memories of sexual abuse. In: Read JD and Lindsay DS (eds.) *Recollection of Trauma: Scientific Evidence and Clinical Practice*, pp. 379–387. New York: Plenum Press.
Seamon JG, Brody N, and Kauff DM (1983a) Affective discrimination of stimuli that are not recognized: Effects of shadowing, masking, and cerebral laterality. *J. Exp. Psychol. Learn.* 9: 544–555.
Seamon JG, Brody N, and Kauff DM (1983b) Affective discrimination of stimuli that are not recognized: II. Effect of delay between study and test. *Bull. Psychon. Soc.* 21: 187–189.
Seamon JG, McKenna PA, and Binder N (1998) The mere exposure effect is differentially sensitive to different judgment tasks. *Conscious. Cogn.* 7: 85–102.
Sharman SJ, Garry M, and Hunt M (2005) Using source cues and familiarity cues to resist imagination inflation. *Acta Psychol.* 120: 227–242.
Shimamura AP and Squire LR (1987) A neuropsychological study of fact memory and source amnesia. *J. Exp. Psychol. Learn.* 13: 464–473.
Sluzenski J, Newcombe N, and Kovacs S (2006) Binding, relational memory, and recall of naturalistic events: A developmental perspective. *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 89–100.
Spaniol J and Bayen UJ (2002) When is schematic knowledge used in source monitoring? *J. Exp. Psychol. Learn.* 28: 631–651.
Sporer SL (2004) Reality monitoring and detection of deception. In: Granhag P-A and Strömwall L (eds.) *The Detection of Deception in Forensic Contexts*, pp. 64–101. Cambridge: Cambridge University Press.
Stark L-J and Perfect TJ (2006) Elaboration inflation: How your ideas become mine. *Appl. Cogn. Psychol.* 20: 641–648.
Starns JJ and Hicks JL (2005) Source dimensions are retrieved independently in multidimensional monitoring tasks. *J. Exp. Psychol. Learn.* 31: 1213–1220.
Tetterton VS and Warren AR (2005) Using witness confidence can impair the ability to detect deception. *Crim. Just. Behav.* 32: 433–451.
Thierry KL, Goh CL, and Pipe M-E (2005) Source recall enhances children's discrimination of seen and heard events. *J. Exp. Psychol. Appl.* 11: 33–44.
Thompson CP, Skowronski JJ, Larsen SF, and Betz A (1996) *Autobiographical Memory: Remembering What and Remembering When*. Mahwah, NJ: Erlbaum.
Toglia MP, Neuschatz JS, and Goodwin KA (1999) Recall accuracy and illusory memories: When more is less. *Memory* 7: 233–256.
Troyer AK, Winocur G, Craik FIM, and Moscovitch M (1999) Source memory and divided attention: Reciprocal costs to primary and secondary tasks. *Neuropsychology* 13: 467–474.
Tulving E (1984) Précis of elements of episodic memory. *Behav. Brain Sci.* 7: 223–268.
Tulving E (1998) Brain/mind correlates of human memory. In: Sabourin M, Craik F, and Robert M (eds.) *Advances in Psychological Science,* vol. 2, pp. 441–460. Hove, UK: Psychology Press.
Tulving E and Thomson DM (1973) Encoding specificity and retrieval processes in episodic memory. *Psychol. Rev.* 80: 352–373.
Wade KA, Sharman SJ, Garry MA, et al. (2007) False claims about false memory research. *Conscious. Cogn.* 16: 18–28.
Welch-Ross MK, Diecidue K, and Miller SA (1997) Young children's understanding of conflicting mental representation predicts suggestibility. *Dev. Psychol.* 33: 43–53.
Westerman DL, Miller JK, and Lloyd ME (2003) Change in perceptual form attenuates the use of the fluency heuristic in recognition. *Mem. Cognit.* 31: 619–629.
Wiggs CL and Martin A (1994) Aging and feature-specific priming of familiar and novel stimuli. *Psychol. Aging* 9: 578–588.
Whittlesea BWA (1993) Illusions of familiarity. *J. Exp. Psychol. Learn.* 19: 1235–1253.
Whittlesea BWA (2002) Two routes to remembering (and another to remembering not. *J. Exp. Psychol. Gen.* 131: 325–348.
Whittlesea BWA and Price JR (2001) Implicit/explicit memory versus analytic/nonanalytic processing: Rethinking the mere exposure effect. *Mem. Cognit.* 29: 234–246.
Whittlesea BWA and Williams LD (1998) Why do strangers feel familiar, but friends don't? A discrepancy-attribution account of feelings of familiarity. *Acta Psychol.* 98: 141–165.
Winkielman P, Halberstadt J, and Fazendeiro T (2004) Prototypes are attractive because they are easy on the mind. *Psychol. Sci.* 17(9): 799–806.
Winograd E (1968) List differentiation as a function of frequency and retention interval. *J. Exp. Psychol.* 76: 1–18.
Wixted JT (2004) On common ground: Jost's (1897) law of forgetting and Ribot's (1881) law of retrograde amnesia. *Psychol. Rev.* 111: 864–879.
Wixted JT (2007) Spotlighting the probative findings: Reply to Parks and Yonelinas (2007). *Psychol. Rev.* 114: 203–209.
Wood G (1978) The knew-it-all-along effect. *J. Exp. Psychol. Hum. Percept. Perform.* 4: 345–353.
Yarmey AD (2000) Retrospective duration estimations for variant and invariant events in field situations. *Appl. Cogn. Psychol.* 14: 45–57.
Yonelinas A (1999) The contribution of recollection and familiarity to recognition and source-memory judgments: A formal dual-process model and an analysis of receiver operating characteristics. *J. Exp. Psychol. Learn.* 25: 1415–1434.
Zaragoza MS and Koshmider JW (1989) Misled subjects may know more than their performance implies. *J. Exp. Psychol. Learn.* 15: 246–255.
Zaragoza MS and Lane SM (1998) Processing resources and eyewitness suggestibility. *Legal Criminol. Psychol.* 3: 305–320.

# 2.20 Metamemory

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Metamemory refers to the processes and structures whereby people are able to examine the content of their memories, either prospectively or retrospectively, and make judgments or commentaries about them. Thus, metamemory is not memory itself, although it may depend critically upon memory. Rather it is the judgments, assessments, or commentaries that are made about memories or learning. These kinds of self-reflective judgments have a long and controversial history. Presumably, for example, when Descartes was engaged in his famous doubting meditation – musing about how his memories or perceptions could have been different than they were, or how he could have been mistaken about them – he was engaging in metacognition. This kind of reflection was taken by him as the basis of all knowledge and the core of our phenomenological selves. Similarly, the introspectionists (with whom behaviorists later took such exception) were, presumably, engaging in what we would now call metacognition. The lack of reliability of their findings was a shortcoming that proved devastating for their method by opening the door for the behaviorists to oust the study of consciousness, at least temporarily, from the domain of respectable topics in psychology. However, the judgmental biases that were the bane of early twentieth century introspectionism are now being studied under the guise of the biases and framing effects that are both systematic and rampant in metacognitive judgments.

That these metamemory judgments can be studied objectively, and reliably, is now apparent, with many hundreds of studies having been directed at issues of human metacognition. Indeed, growing interest and research from a metacognitive perspective – with its emphasis on people's memory-based attributions – can be considered one of the most significant developments in the science of psychology in this new century. Both the processes that underlie the judgments themselves and the implications that these judgments have for self-guided control of learning are yielding to investigation. Current methods promise both enhanced understanding of impairments in metacognition and also the possibility of remedying certain biases to enable people to better assess and control their own learning.

How these judgments are made has been the focus of much research, and some of these processes are detailed shortly. Classically, three types of judgments have formed the core of metamemory research: Feeling-of-knowing judgments, tip-of-the-tongue judgments, and judgments of learning. Although there may be some differences between feeling-of-knowing and tip-of-the-tongue judgments (see Schwartz, 2006), their similarities outweigh their differences, and we treat them together. However, the restriction to these so-called classic judgments is arbitrary, because metamemory refers to any judgment that is about a memory. The reflective quality is what is important in the definition. Thus, other judgments such as confidence judgments, source judgments, recognition judgments, and remember/know judgments are also properly considered to be metamemory. Indeed, any attribution about memory is properly considered to be metamemory, and one may even argue that all memory output relies at least partially on metamemory. For instance, if you covertly recall that the word needle was on a list of words that you just tried to memorize or that Dr. Case told me that the medication would have no side effect, you would likely not report the word needle or recommend the medication to a friend if you were not sufficiently confident in your memory (Koriat and Goldsmith, 1996). Accordingly, we also briefly discuss other memory judgments – in particular, source judgments and remember/know judgments – in the same context as the classical metamemory judgments.

**Figure 1** provides an illustration of what is meant by metamemory. Nelson and Narens (1990), in a highly influential paper, argued that metacognition entailed two mental levels: an object level and a

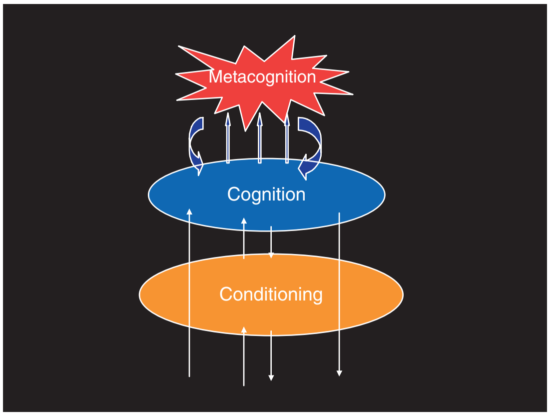


**Figure 1** A model of the relations among metacognition, cognition, and conditioning. The model shows that the metacognitive level both monitors (up arrows) and controls (down, thick arrows) the contents of the cognitive level.

metalevel. The object level consists of the memories themselves. The metalevel involves monitoring the object level, such as reflecting upon memories and ongoing learning. When the object level is memory, such monitoring is measured by feeling-of-knowing judgments, judgments of learning, source judgments, or judgments about whether the individual remembers the event explicitly or only knows that it must have happened. The requirement is that the object of the judgment be a mental event, rather than something that is present in the environment. Many animals can make judgments about the world, but few are capable of reflecting on the objects of their minds, such as their memories (see Terrace and Metcalfe, 2005). The ability to so reflect indicates a fundamentally different kind of mental life for the animals that have it.

As can also be seen from the figure (arrows flowing from metacognition to cognition), metacognition is presumably necessary for high-level control of one's own mental processes and memories. Without knowledge of what one does not know, one could not be expected to take action to remedy the situation by, say, allocating differential study opportunities, rehearsal, or time. The metacognitive individual can choose to mould his or her own mind by self-initiated study processes, thereby learning things under self-control rather than only under stimulus control. To regulate effectively, such self-guided learning requires accurate metacognitions, of course, but it also depends on their appropriate use. If one's metacognitive judgments are inaccurate, self-regulated study could be suboptimal because the person does not know what he or she does not know. Such metacognitive failure could result because of immature metacognition capabilities or because of an impairment due to illness, stroke, or head injury. Distortions in metacognition also occur, even in normal and unimpaired people, because they are blinded by some illusion of metacognition due to the circumstances of the task at hand. Many metacognitive illusions – or biases – have now been documented by researchers (Bjork, 1994), and understanding and finding methods to debias them is fundamental if self-guided study is to succeed (Thiede et al., 2003). However, self-controlled learning and memory processing can also go awry even when a person's metacognitions themselves are excellent, if those metacognitions are not converted into optimal control strategies. One could know what one knows, but still do the wrong thing. Finally, even if one knows what one knows, and one knows what to do about it, the actual implementation of the control knowledge could be faulty – leaving a fully metacognitive person still unable to effectively control their own learning and memory.

Whereas early research on metacognition and control focused almost exclusively on people's judgments about their memories, with the often-stated hope that this would lead to enhanced learning, recent research is increasingly aimed at the control aspect of meta-level awareness. In the section that follows, we focus on the judgments themselves, first, and on theories about how those judgments are made. We then turn to how those judgments are put to use in controlling learning and memory.

## 2.20.1 Metamemory Paradigms

### 2.20.1.1 Feeling-of-Knowing Judgments

The feeling-of-knowing judgment was the first to be systematically explored experimentally, by Joseph Hart, in 1965. Hart gave people a variety of general information questions to answer. When they could not answer a question, he asked them whether they felt they knew the answer anyway. The feeling that they knew it corresponded to their later choosing the correct answer on a recognition memory test. This paradigm posed a puzzle: How is it that people could ostensibly not know, as evidenced by their failure to produce the answer, and yet still be able to predict accurately whether they would know in the future, as evidenced by the correlations that were well above chance between their predictions and subsequent performance?

This finding of above-chance predictive accuracy has been replicated hundreds of times, so there is no doubt as to its reliability. The research in recent years has been directed not at establishing the predictive accuracy of feeling-of-knowing judgments but, rather, at understanding what cues people are using that give rise to it. Several theories have addressed this puzzle of seemingly not knowing and knowing at the same time, that is, how people are able to correctly predict what they will know in the future, when at the moment they are unable to retrieve the correct answer.

#### *2.20.1.1.1 Theories*

Whereas some early theories suggested that the person might have direct access to subliminal traces, all modern theories are basically heuristic in nature; that is, they assume that people have explicit access to some information that notably may be correct or incorrect, diagnostic or nondiagnostic, and that their feeling-of-knowing judgments are based on this information. Thus, while all current theories of this metamemory paradigm (and, indeed, of all metamemory paradigms) are heuristic theories, they differ in the exact heuristic that they propose people are using to make metamemory judgments.

***2.20.1.1.1.(i) Domain and cue familiarity*** A logical possibility for the basis of feeling-of-knowing judgments is that people assess the familiarity of the cue (i.e., the question itself) or the domain of the question. Greater familiarity leads to higher judgments, that is, more confidence that a currently unretrieved answer will later be recognized. Concerning domain familiarity, even though people may be unable to immediately answer a question such as "Who painted *The Sunflowers*?," they may be able to assess how much they know about art and make a reasonable judgment on that basis. If they know something about art, they may be able to narrow down the field in a recognition test and eliminate incorrect alternatives. Thus, this kind of familiarity with the domain of the question may both be used to make a feeling-of-knowing judgment and be diagnostic, because, in general, strategic multiple-choice decision making will be better in well-known than in little-known domains. Thus, the person may not know who painted a particular painting but may nevertheless have a quite good idea of who did not do so, and such knowledge will help them on the test.

Glenberg and Epstein (1987) conducted an experiment in which people were selected for participation based on their expertise in various domains. They were then presented with texts to read that were either in their own domain or not. They found that people made higher judgments of knowing on those passages that were within their own area of expertise, thereby indicating that this kind of knowledge about the domain is one of the cues or heuristics that people use in making their judgments. Surprisingly, however, in this particular case, experts were not well calibrated when making judgments within their own domain. The mystery of this unexpected result remains unresolved even today. Finally, because many studies of feeling of knowing have been conducted with general information questions, and there are several domains of knowledge implicated in these questions (e.g., American history, old movies, sports, geology, capitals of various countries, etc.), knowledge of the types of general knowledge one knows most about could be quite predictive of recognizing the correct answers.

Concerning cue familiarity, Reder and her colleagues (e.g., Reder, 1987; Reder and Ritter, 1992; Miner and Reder, 1994) conducted a series of experiments in which they showed that the familiarity of the cue influenced feeling-of-knowing judgments. For instance, Reder and Ritter (1992) presented participants with math problems (e.g., 113 + 29 = ?) and had them quickly decide whether they wanted to retrieve or compute answers to each one. Prior to making a decision, the cue item was primed, without altering the target answer. Thus, in a math problem such as 113 + 29, they would prime the cue by giving another problem such as 113 * 29. When 113 + 29 = ? was presented, people then hit a button if they wanted to retrieve the answer as compared to compute the answer. If they already knew the answer, it would behoove them (because they would gain a greater reward) to hit the retrieve button, indicating that they could quickly retrieve the answer from memory. The interesting finding, from the perspective of the cue-familiarity heuristic, is that when the cues had been primed, people were more likely to indicate that they could retrieve the answer, even though such priming might even have hurt the retrieval of the correct answer. In a similar manner, Metcalfe et al. (1993) found that cue priming of verbal pairs influenced the feeling of knowing without altering target retrievability. In particular, they showed that the crucial factor influencing the magnitude of feeling-of-knowing judgments was the number of repetitions of the cue (which presumably would boost cue familiarity), rather than the retrievability of the sought-after target.

Whereas these and other studies (e.g., Maki, 1999; Eakin, 2005) clearly implicate the familiarity of the cue as one heuristic that people use in making metamemory judgments, evidence also suggests that partial information retrieved about the target is important.

***2.20.1.1.1.(ii) Partial target accessibility*** The other main source of information for making feeling-of-knowing judgments is partial knowledge about the target. Perhaps one recalls that the answer to the sunflower question given earlier is an impressionist, and maybe even that there is a 'G' in the name. Even with this information, the person may be unable to give the answer. However, such partial target information may be sufficient that he or she will assign the item a high feeling of knowing. Such partial information, which is about the target itself, may be insufficient to allow the person to express the target item but may, nevertheless, indicate (often correctly) that he or she will be able to select the target in a multiple-choice test. (The only problem the person might experience in the present case could be in distinguishing Gauguin from Van Gogh, should both be present in the list). Thus, if partial or fragmentary target information is retrieved, it may be used to indicate that people will know the answer (and hence be related to high feeling-of-knowing judgments).

Koriat (1993) conducted experiments in which the to-be-remembered items were four-letter nonword strings. He showed a positive correlation between the number of letters the person could recall and their feeling of knowing rating. Of course, having three letters rather than just one was highly predictive of whether they would be able to pick the right answer from the set of alternatives offered, and so the predictive accuracy of this particular information-based metacognition was extremely high. The experiment was designed such that a 20-questions strategy was highly diagnostic, because one could eliminate half of the multiple-choice test alternatives with every letter correctly remembered. Playing 20 questions, and deliberatively assigning feeling-of-knowing judgments on the basis of the knowledge that partial information would allow them to eliminate alternatives in the test, is a logical possibility, and one that should work fairly well in the world. Phenomenologically, the judgments often feel more intuitive and less deliberative; however, even if people are less analytic about making these judgments than Koriat's experiments would suggest, if one has partial information, such as the first letter of the target, such information may give rise to a diffuse feeling that one knows more than nothing, and in many cases, one would be correct to inflate one's feeling of knowing.

It seems likely that the two mechanisms – cue familiarity and partial target information – account for most of the variability in feeling-of-knowing judgments. If so, hybrid models that describe how both cues combine (e.g., Leibert and Nelson, 1998; Koriat and Levy-Sadot, 2001) will likely fare well and are worthy of further exploration.

### 2.20.1.2 Tip-of-the-Tongue States

While overlapping in many respects with feeling-of-knowing judgments, tip-of-the-tongue judgments focus more directly on highly accessible partial information, and they appear less inferential in nature (for a general review, *See* Chapter 2.22). Nevertheless, even if tip-of-the-tongue states merely represent very strong feelings of knowing, tip-of-the-tongue judgments have been investigated extensively (and separately from feeling-of-knowing judgments) because they occur so commonly in everyone's lives (Schwartz, 1999). In fact, well before the term 'metamemory' was coined, and before other metamemory judgments were scrutinized, the tip-of-the-tongue state captured the attention of William James (1890/1981). In his now-famous quote, James wrote: "Suppose we try to recall a forgotten name. The state of our consciousness is peculiar. There is a gap therein; but no mere gap. It is a gap that is intensely active. A sort of wraith of the name is in it, beckoning us in a given direction, making us at moments tingle with the sense of our closeness.… The rhythm of a lost word may be there without a sound to clothe it; or the evanescence sense of something which is the initial vowel or consonant may mock us fitfully, without growing more distinct" (James, 1890/1981: 243–244).

Schwartz (1999) has conducted a survey of 51 language groups and found that in the majority of them, there is an expression for what, in English, is called the tip-of-the-tongue state, though the exact expression varies slightly. In Korean, for example, this state is provocatively called "sparkling at the end of the tongue." This state seems to be almost universally experienced.

#### 2.20.1.2.1 Theories

**2.20.1.2.1.(i) Partial target access** In a manner that is similar to the target access view of feelings of knowing, the dominant theory of tip of the tongues is that they reflect partial target access. In support of this view, a number of studies have shown that people are able to report the number of syllables in the to-be-retrieved word, some aspects of semantic content, or its first letter (for a review, see Schwartz, 2002).

**2.20.1.2.1.(ii) Lexical access without phonological access** Burke et al. (1991; see James and Burke, 2000) have proposed that a semantic level of representation of a sought-after word feeds to an articulatory/phonological level, which is necessary for word retrieval and output, and that the two representations can be dissociated. One dissociation is reflected by a tip-of-the-tongue state when the individual has complete or partial access at the semantic or lexical level, without being able to translate that activation into a phonological form that allows retrieval – or output – of the sought-after word. According to this model, the individual really can know an answer without being able to articulate it. Older adults seem to exhibit this phenomenon whereby an impairment occurs in phonological translation, which results in more tip-of-the-tongue states (for a recent review, see Schwartz and Frazier, 2005).

A prediction of this model is also supported by evidence from Metcalfe et al. (1995), who described an anomic patient who had difficulties retrieving words. In particular, this patient (HW), after experiencing a severe stroke, was able to converse intelligently but was unable to articulate the words for nearly all specific nouns, verbs, or adjectives when so requested. Thus, if asked to fill in the correct answer "One ______ the Thanksgiving turkey by brushing butter on while it is roasting," "The precious gem that is red is the _____," "The name of people who explore caves is ______," or even "Sirius is the ________ star in the sky excluding the sun," HW could not say bastes, ruby, spelunker, or brightest. However, he expressed a strong tip-of-the-tongue for these words. When he was later given a recognition test, he was able to pick the correct alternative with an accuracy better than that of Dartmouth College students, indicating that he knew the words he was seeking (i.e., he had semantic knowledge or lexical access) but could not articulate them. Burke et al.'s model eloquently explains HW's deficit.

**2.20.1.2.1.(iii) Blocking** One phenomenon seen in conjunction with tip-of-the-tongue states is that people often report that an incorrect response persistently comes to mind. This persistent alternative is usually called a blocker. We suspect that what makes tip of the tongues frustrating at times is that people in a blocked tip-of-the-tongue state know perfectly well that what keeps persistently coming to mind is wrong. Blocked tip of the tongues differ from nonblocked tip of the tongues insofar as people's phenomenology is different. In addition, it has been shown that blocked tip of the tongues tend to be more difficult to resolve than tip of the tongues without a blocker (Burke et al., 1991; Reason and Lucas, 1984). Researchers have thought that blockers actively keep people from accessing the correct answer. However, recent research by Kornell and Metcalfe (2007) indicates that this active blocking role of the so-called blockers is incorrect. In particular, they conducted an experiment to investigate the idea that blockers impaired performance, as is assumed both in the tip-of-the-tongue literature (Jones, 1989) and in the insight literature, where a similar phenomenon is thought to occur (Mayer, 1995). Theorists have stated that people need to incubate (e.g., take a break to think about something unrelated to the problem) in both a problem-solving attempt or when attempting to retrieve a sought-after answer when in tip-of-the-tongue state. If a persistent alternative came to mind originally (which is supposed to be actively interfering with the generation of the correct solution), this break may allow one to forget it. If so, the off time will allow the problem-solver to overcome the harmful blocker and retrieve a correct solution.

To test this idea, Kornell and Metcalfe (2007) asked people to state whether their tip-of-the-tongue states included a blocker or not. The subjects then either continued to try to solve the problem or waited until the end of the experimental session for the additional minutes that they were assigned to attempt to solve the problem. As in the past literature, blocked tip of the tongues were resolved with a frequency that was lower than that of nonblocked tip of the tongues. Furthermore, consistent with the reminiscence literature, people answered more questions correctly at a delay than immediately. However, the delay interval did not particularly help the blocked tip of the tongues, as compared to the nonblocked tip of the tongues, as should have been the case had the blockers themselves kept the correct answer from appearing. Also, the blockers were forgotten over the delay interval. Thus, the delay interval did, effectively, get the blockers out of mind (as presumably should have been necessary to obviate their deleterious effect). But that made no difference for the rate of resolution, indicating that the so-called blockers do not really block. Kornell and Metcalfe (2007) favored a road sign view of blockers; they are in the person's semantic network, and the person might well articulate them in their quest for the correct answer, but they do not actively participate in the process. Whether they are accessed or not has no effect on the probability of retrieving the target.

#### *2.20.1.2.2 Function of feeling-of-knowing and tip-of-the-tongue states*

Little emphasis has been placed on the question of why people have feeling-of-knowing states or tip of the tongues. Perhaps the nagging emotional quality of the tip of the tongues is motivational and keeps people seeking an answer that otherwise they would not try to find. Similarly, Reder and Ritter (1992) have suggested that people's feelings of knowing indicate to them that there is something in memory to be found, and hence these feeling states – especially the fast feelings of knowing – provide information that people use to determine whether they will or will not attempt retrieval. Systematic research on whether and how feelings of knowing and tip of the tongues guide decision making and retrieval is needed.

### 2.20.1.3 Judgments of Learning

Judgments of learning are assessments that people make, either while in the course of learning, or afterwards, about how well they have learned the particular target materials under question. These judgments are thought to be of fundamental importance because the monitoring of study tapped by them is presumably used by a person to determine whether or not to study (e.g., Thiede and Dunlosky, 1999; Son and Metcalfe, 2000). Thus, if the judgments are faulty, so too will be people's subsequent study behavior. It is thought that with biased judgments, ultimately people's learning will be less than optimal.

Judgments of learning can be made in a cumulative manner, whereby the participant is asked to assess the degree of learning over an entire list or session, or they can be made on an item-by-item basis. For instance, when studying a list of 20 paired associates (e.g., dog–spoon), participants may be asked to predict how many out of 20 they will correctly recall when later tested (e.g., dog–?). While studying, they may make item-by-item judgments of learning, where participants are shown either only the cue (e.g., dog–?) or both the cue and response (e.g., dog–spoon) and are asked to predict the likelihood that the correct response (i.e., spoon) will be recalled. Item-by-item judgments of learning can be made either immediately while the person is learning or directly following that learning, or they can be made at a delay. As compared to aggregate judgments, the item-by-item judgments of learning currently have received the most empirical and theoretical attention in the field (for a comparison of the two judgments, see Dunlosky and Hertzog, 2000), so we shall largely restrict our review to them.

Two major findings have held up extremely well over the course of the last decade of research and have become the target of much further investigation. First, delayed, cue-only judgments of learning are highly accurate. The gamma correlations relating people's judgment-of-learning ratings to their later performance are often in the 0.90 range. In contrast, immediate judgments of learning and delayed judgments of learning when the cue and target are also given are often rather inaccurate, and it is not uncommon to see the analogous gamma correlations being around +0.30. The reasons for these differences, which are tightly related to theories of how people make judgments of learning in these different conditions, are outlined below. The second major finding is that whereas first-trial immediate judgments of learning (and aggregated judgments) are often overconfident (i.e., their mean value is higher than the mean performance that people exhibit when they are tested), judgments of learning made on a second study-test trial over the same items are nearly always underconfident. Again, we discuss the explanations researchers have isolated (and those potential reasons that they have discredited) in the theoretical section that follows, titled 'Theories of the delayed-judgment-of-learning effect.'

#### 2.20.1.3.1 Theories of the delayed judgment-of-learning effect

Four theories have been directed at the issue of why accuracy (as measured by resolution or the correlation relating judgments of learning to subsequent performance) is substantially greater for delayed than immediate judgments of learning, which has been dubbed the delayed judgment-of-learning effect (Nelson and Dunlosky, 1991). The first was the monitoring dual memories hypothesis, and the second is the transfer-appropriate processing framework. The third is the self-fulfilling prophecy hypothesis, whereby the judgment itself alters memory, and this alteration is responsible for the boost in accuracy for delayed judgments of learning. The fourth is a stochastic drift model.

***2.20.1.3.1.(i) Monitoring-dual-memories hypothesis*** Nelson and Dunlosky's (1991) monitoring-dual-memories hypothesis assumes that judgments of learning are made by retrieving information from both short-term memory (STM) and long-term memory (LTM). In the immediate-judgment-of-learning condition, STM information is highly accessible, but it is transient and does not reflect what information will be available at final test. The presence of this STM information during the judgment, therefore, adds nondiagnostic information to the judgment, thereby reducing the accuracy of the judgments of learning. In the delayed-judgment-of-learning case, people are thought to base their judgments primarily on the retrieval of information from LTM. This retrieved information is more accurate in predicting final test performance, which is also based on LTM alone. This first explanation has a basic similarity to the second explanation – the transfer-appropriate processing explanation – insofar as both posit that the information that the person bases the judgment on is more similar to the information at time of test for the delayed than immediate judgments of learning.

***2.20.1.3.1.(ii) Transfer-appropriate monitoring hypothesis*** The second explanation – a transfer-appropriate processing view – proposes that the delayed-judgment-of-learning effect occurs because of differences between the two judgment-of-learning conditions in the degree of contextual match from the time of the judgment to the time of the test (Begg et al., 1989; Dunlosky and Nelson, 1997). Making a judgment of learning in a situation that is as similar as possible to that of the test should maximize its accuracy. Insofar as the retrieval attempt, which is thought to be the critical information on which the judgment of learning is based, is more similar between a delayed test and a delayed judgment of learning than between a delayed test and an immediate judgment of learning, the delayed judgments are predicted to be more accurate.

***2.20.1.3.1.(iii) Self-fulfilling prophecy hypothesis*** The third explanation locates the increase in gamma accuracy between immediate and delayed judgments of learning in a differential change in memory with immediate and delayed judgments of learning that comes with making the judgment itself (Spellman and Bjork, 1992; Kimball and Metcalfe, 2003). This third theory has been called a Heisenberg explanation or the self-fulfilling prophecy hypothesis. An assumption here is that people attempt retrieval to make their judgments of learning but, in the delayed-judgment-of-learning condition, are successful with only some of those attempts. The practice elicited by cue-only delayed judgments of learning enhances memory for retrieved items, but only some items are retrieved at the delay. Moreover, the items that receive this memory boost are not distributed randomly across the judgment of learning range, but rather are those given high judgments of learning, because the basis of the judgment is whether or not the person is able to retrieve. Those items that people fail to retrieve are given low judgments of learning and get no boost in study. Thus, the high-judgment-of-learning items benefit from an extra (spaced) study trial, while the low-judgment-of-learning items receive no additional practice and get no memory boost. This differential study has an effect on memory that bolsters the predictive value of the ratings only in the delayed-judgment-of-learning condition. In the immediate-judgment-of-learning condition, virtually all items are recalled during the judgment (e.g., Nelson et al., 2004), which occurs immediately after study and has little memorial effect. In addition, being uniform across the entire judgment-of-learning range, this immediate retrieval does not make the high judgments of learning more memorable or the low judgments of learning less memorable.

***2.20.1.3.1.(iv) Stochastic drift model*** Finally, Sikstrom and Jonsson (2005) propose (in a manner related to the monitoring dual memories hypothesis) that the accuracy difference is because memory strength for any given item can be decomposed into exponential functions with slow and fast components. The drift from these decay processes from time of judgments to time of test is large for immediate judgments of learning, resulting in low predictability, but is smaller for the delayed judgments, resulting in high predictability. This model is most welcome in the field for two reasons: First, because it is a much needed formal model of the processes thought to underlie the judgments and their consequences, and second, because it makes new predictions about outcomes.

***2.20.1.3.1.(v) Status of theories for the delayed-judgment-of-learning effect*** Although considerable empirical work has been conducted to evaluate these theories (either in isolation or in competition), it is currently premature to declare one as a clear winner. Nevertheless, albeit intuitive, the transfer-appropriate monitoring hypothesis has been repeatedly disconfirmed (e.g., see Weaver and Kelemen, 2003; Dunlosky et al., 2005b). Moreover, recent modeling of the delayed-judgment-of-learning effect suggests that both a monitoring-dual-memories component and a Heisenberg-style component may be required to fully account for the effect (Jang et al., 2006).

All four of the theories explain the delayed judgment-of-learning effect by assuming that people make their judgments by using the heuristic of trying to retrieve the target, at least in the delayed case. None of these models take into account the possibility that other cues may be used to make the delayed judgments of learning. However, Son and Metcalfe (2005) have shown that people sometimes make very fast delayed judgments of learning and that these fast judgments of learning are probably not based on retrieval or attempted retrieval of the target. They showed that there were notable differences in the results when people were simply asked to make delayed judgments of learning as compared to when they were asked to attempt to retrieve the target immediately prior to making each judgment of learning (e.g., for detailed application of this method, see Nelson et al., 2004). In particular, the very fast judgments of learning drop out in the latter case, suggesting that normally people are doing something to produce these fast judgments of learning that they are not doing when they explicitly try to retrieve the target. They suggested that people are basing these fast low judgments of learning on a lack of familiarity with the cue, and that when the cue is unfamiliar, people do not bother to try to retrieve the target. In this way, they proposed a two-factor hypothesis in which familiarity and retrieval interact to influence people's judgments of learning.

Benjamin (2005) provided support for a two-factor hypothesis by showing that when people are time pressured, factors that affect cue familiarity come into play in their judgments of learning. When they are not time pressured, factors affecting the retrievability of the target are influential. Note that these are the same two cues that people use in making feeling-of-knowing judgments. With delayed judgments of learning, these cues appear to be used in a specific order. First, people assess the familiarity of the cue. If it is unfamiliar, they give a low judgment of learning. If it is familiar, they go on to the second stage, in which they attempt retrieval of the target. If they cannot do so, they give the item a relatively low judgment of learning; if they can do so, they give it a high judgment of learning. Given the evidence for the second factor in delayed judgments of learning, it appears that none of the four theories can fully account for the judgments. Regardless of its ultimate explanation, however, there is general agreement that delayed judgments of learning may be quite valuable in helping people both accurately monitor and effectively control their learning (Bjork, 1994).

The heuristics used when people make immediate judgments of learning are less straightforward than those used in making delayed judgments of learning. Data indicate that a variety of cues may play a role, such as the fluency of processing words during study (Begg et al., 1989), the fluency of generating study strategies (Hertzog et al., 2003), the relatedness of words within paired associates and across individual words (e.g., Koriat, 1997; Dunlosky and Matvey, 2001; Matvey et al., 2006), and memory for the outcome of previous tests (Finn and Metcalfe, 2007, 2008), among many others (for a review, see Koriat, 1997). Whereas some of these cues, clearly, must have some predictive value – the gamma correlations are nearly always greater than zero – they are typically less diagnostic than the cues used in delayed judgments.

#### *2.20.1.3.2 Theories of the underconfidence-with-practice effect*

The second major finding within the judgment-of-learning literature is that although people's judgments of learning tend to be overconfident on the first trial, by the second trial, there is a shift to underconfidence that persists on subsequent trials. Much research has focused on this underconfidence-with-practice effect, and a number of efforts to explain it, based on exactly how people make judgments of learning, have been proposed (as shown in **Figure 2**, from Koriat et al., 2002). Besides drawing attention to the underconfidence-with-practice effect, Koriat et al. (2002) demonstrated that it persisted despite a variety of experimental manipulations that might otherwise provide explanations of it. For example, feedback about performance on a prior trial had no effect. Both incorrectly and correctly recalled Trial 1 items showed underconfidence on Trial 2. Although this finding suggests that past test performance may not drive the effect, Finn and Metcalfe (2007) have shown that the underconfidence is significantly larger for items that were incorrect on Trial 1 than for items that were correct on Trial 1, qualifying the earlier conclusion that Trial 1 performance was irrelevant.

One possible explanation for the underconfidence-with-practice effect is that people are underconfident because they have insufficient control over their own study to learn because the duration of study for each item is typically under experimental control. In contrast to this possibility, the underconfidence-with-practice effect was found when the study time allowed for each item was fixed or when it was self-paced (Koriat et al., 2002). Perhaps people just do not care and make the judgments without due consideration. However, even with incentives given for making accurate judgments – a manipulation that increases Trial 1 judgment of learning accuracy – the underconfidence-with-practice effect persisted. Thus, mere laziness on the part of participants does not appear to be the answer.

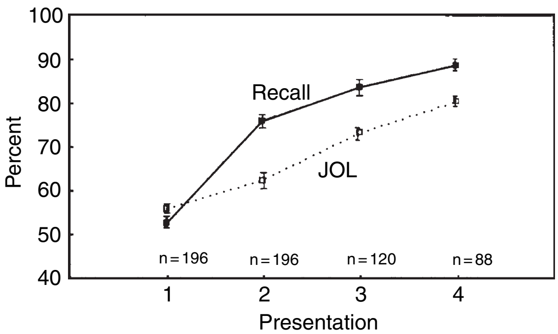


**Figure 2** Illustration of the underconfidence-with-practice effect, with judgments of learning (JOL) showing overconfidence on an initial study trial and underconfidence on subsequent trials. From Koriat A, Sheffer L, and Ma'ayan H (2002) Comparing objective and subjective learning curves: Judgments of learning exhibit increased underconfidence with practice. *J. Exp. Psychol. Gen.* 131(2): 147–162.

Numerous studies have shown that easy materials tend to result in less overconfidence than difficult materials (Lichtenstein and Fischhoff, 1977), so perhaps the underconfidence-with-practice effect is just another manifestation of item effects described in the confidence literature. Although possible, Koriat et al. (2002) reported that both easy and difficult items showed the underconfidence-with-practice effect. And it does not appear to be attributable to the undue effects of retrieval fluency from the first test trials (Serra and Dunlosky, 2005). Their idea was that people might assign low judgments of learning to items that were recalled on Trial 1, slowly or with great difficulty. The data, however, did not support this hypothesis.

One hint about the underconfidence-with-practice effect comes from the finding that immediate judgments of learning show the effect, whereas delayed judgments of learning do not (e.g., Meeter and Nelson, 2003; Koriat and Ma'ayan, 2005; Scheck and Nelson, 2005; Koriat et al., 2006; Finn and Metcalfe, 2007). In fact, early evidence relevant to the underconfidence-with-practice effect involved delayed judgments of learning and did not demonstrate the effect (Dunlosky and Connor, 1997). Meeter and Nelson (2003) showed only a 1% difference between delayed judgments and recall performance on Trial 2. Serra and Dunlosky (2005) showed underconfidence for both delayed and immediate judgments but a much greater shift toward underconfidence across trials for immediate judgments. Koriat et al.'s (2006) data showed overconfidence with delayed judgments of learning, though the difference from calibration was slight. Taken together, these reports suggest that delayed judgments of learning are not underconfident but, rather, are very close to being perfectly calibrated. Immediate judgments of learning, however, are nearly always underconfident after the first study-test trial.

As discussed, one difference between immediate judgments of learning and delayed judgments of learning is that people are very likely to rely on different heuristics in making the two different judgments. In the former case, as described earlier, they rely primarily on retrieval of the target item (with some reliance on familiarity of the cue). In the latter case, though, the heuristics are less clear. Finn and Metcalfe (2007) have proposed that use of the Memory for Past Test heuristic selectively in the immediate judgment of learning case, could account for much of the underconfidence-with-practice effect. The idea is that when people make second-trial judgments of learning they think back to whether they remembered that particular item in the past test. If they did, they give it a high judgment of learning. If they did not, they give it a low judgment of learning. If people were using this heuristic, they would tend to underestimate current trial performance insofar as it ignores the new learning in which the person has just engaged. Thus, they would be underconfident. The relationship between second-trial judgments of learning and Trial 1 performance would be expected to be stronger than the relationship between second-trial judgments of learning and Trial 2 performance, which it is (King et al., 1980). Furthermore, when Trial 1 test was manipulated independently of Trial 2 test, people's judgments of learning gravitated toward their manipulated first trial test performance (Finn and Metcalfe, 2008). And finally, when people were asked to simply report what they did to make the judgment, reliance on first trial test performance was a frequently given reason for the judgment given (Dunlosky and Serra, 2006). Thus, the use of this heuristic appears to be a viable candidate for explanation of the underconfidence-with-practice effect, though there are no doubt other factors that contribute to people's second-trial immediate judgments of learning (e.g., Kelley and Muller, 2006).

#### *2.20.1.3.3 Function of judgments of learning*

It is commonly believed that judgments of learning are of critical importance in learning insofar as they determine what people will choose to study and for how long they will persist (e.g., Nelson and Narens, 1990; Nelson and Dunlosky, 1991; Mazzoni and Cornoldi, 1993; Nelson and Narens, 1994; Benjamin et al., 1998; Koriat, 2000; Metcalfe, 2000). If these judgments of learning are accurate, then people will be in a position to choose to study the items that will result in optimal learning. If they are biased, or inaccurate, however, they will be unable to make such optimal choices.

Although the available evidence suggests that judgments of learning in part drive the allocation of study time, this evidence has been largely correlational, so direct experimental evidence is needed to more definitively establish that when metacognitions are manipulated people's study choice follows. Nevertheless, some demonstrations show that when people with inadequate metacognitions have been induced to make more accurate metacognitive judgments, their learning is improved. For instance, Thiede et al. (2003) had students study paragraphs and make a judgment of learning for each. Before making a judgment for a paragraph, participants were asked to generate five keywords about the paragraph that captured its essence. One group generated keywords (and made judgments) immediately after reading each paragraph, whereas another group did so after all the paragraphs were read. After reading and judging the paragraphs, (1) a test was administered about the content for each of the paragraphs, (2) participants were allowed to select paragraphs for restudy, (3) they restudied chosen texts, and (4) a final test was administered.

Several outcomes are notable. First, judgment-of-learning accuracy for predicting first-test performance was substantially greater for the delayed judgment ($+0.70$) than for the immediate group ($<+0.30$). Second, whereas first-test performance did not differ for the groups (both had a mean value a bit greater than $+0.45$ questions correct), the final test performance was much better for the delayed group (approximately 0.65 correct) than for the immediate group (approximately 0.50). Why such a difference? Fine-grained analyses showed that the delayed group, who had much better judgment accuracy, was more likely to choose paragraphs for restudy that they did not know well, and hence they made the greatest gains in learning during restudy. Without the ability to isolate these less well-known items, students' metacognitive judgments simply did not help them effectively regulate their learning. Thus, preliminary evidence is suggestive that people's metacognitions are used to allocate restudy and, more important, that at least one condition that boosts accuracy can also support more effective learning (for other relevant evidence, see Dunlosky et al., 2005a).

### 2.20.1.4 Source Judgments

Source judgments refer to attributions about the origins of our thoughts and memories (Johnson and Mitchell, 2002; for a review, *See* Chapter 2.19). As such, these judgments are metacognitive, being judgments about other cognitions. Such judgments are targeted when a person is asked who said a particular statement, where they heard something, whether they said something or someone else did, whether they saw the defendant rob the store or only saw him on the sidewalk afterwards, and so on.

Failures of source memory can have profound consequences. One such consequence is unconscious plagiarism. Another is a breakdown in reality monitoring, such as may be seen in psychiatric syndromes such as schizophrenia, in which a person cannot monitor whether the source is internal or external, and in which reality breaks down. Accurate source monitoring is critical for the eyewitness to a crime, but unfortunately, this kind of metacognition can be highly inaccurate.

#### *2.20.1.4.1 Theories of source monitoring*

Johnson and Raye (1981; Johnson, 1983; Johnson et al., 1993) have formulated a model, called MEM (for multiple-entry modular memory system framework), which brings together many of the findings from the source literature in a coherent and elegant form. The consensus view, articulated in the MEM model, of the mechanisms underlying source judgments is that they, like other metacognitive judgments, are based on heuristics. When asked to assess a source, people use what information comes to mind to make the judgments, and this information itself can vary radically depending upon a number of factors. For example, if two potential sources are highly similar to one another, the memory will be highly confusable and the resultant judgment will be more difficult and error prone. If they are quite different from one another, the task is easier. So, if one has to say whether Mary or Lynn said a particular sentence, if Mary is female and Lynn is male, the task is much easier than if both are female (Ferguson et al., 1992). If the two sources are spatially discrete, once again the task is easier than if they are overlapping (Ferguson et al., 1992). Physical differences of this sort have been well documented, are systematic, and conform very nicely to one's intuitions.

Interestingly, though, it is not only the conditions in the world that determine how confusable the sources of different events will be but also the individual's mental capabilities and mental operations that play a part. If a person is readily able to construct vivid images – being able to mentally see a turkey when the word turkey is read – and if he or she automatically encodes concrete nouns as images, then the source distinction of whether a word or a picture was presented will be more difficult than for a different person whose imagery capabilities are less well developed (Johnson et al., 1979). If a person is told to imagine words being spoken in a particular person's voice, which is similar to the speaker's, as opposed to imaging in a voice less similar, the source judgments will be affected (Johnson et al., 1979). The vividness of a person's imagination, then, can have a dramatic effect on whether things that actually happened are confused with those that were only imagined.

Since Johnson's seminal research in the field, the literature has grown extensively, with research involving everything from basic cognitive theory to the neurological underpinnings of source memory. Certainly, this literature is too broad to cover here (for a review, see Johnson et al., 1993; Mitchell and Johnson, 2000; Johnson and Mitchell, 2002), but in contrast to many other coverages of metamemory, we wanted to draw some attention here to this very important, and pervasive monitoring skill.

### 2.20.1.5 Remember/Know Judgments

People can distinguish between events or items that they remember (i.e., for which they have a clear and distinct recollection not only for the target material itself but also for the circumstances of having learned it) versus those that they only know. For example, one might remember one's first iPod, including the circumstances under which one obtained it, and so on, but only have a feeling that they know they saw such-and-such a person some time ago without being able to recall the specific episode. In typical experiments, participants will study a list of words (e.g., pencil, table, football, etc.). After study, the words are presented again mixed with new words, and participants are asked whether each item was originally presented (i.e., a standard recognition judgment), and then whether they recollect that it was presented or merely know that it was presented. In this example, you may state that you recognize that both pencil and football had been presented, but when asked for a remember/know judgment, you may recollect seeing football because you recollected that when it was originally presented you thought of your favorite football team (e.g., the Denver Broncos), whereas you have no recollections about pencil but just have a diffuse feeling, knowing that it was presented.

Being able to tell the difference between remembering and knowing, that is, the ability to make this particular judgment about a memory, is a category of metacognition that is thought to have significance for our understanding of human consciousness (for a general review on remember-know judgments, *See* Chapter 2.17). Events that are recollected are thought to be true memories and to exemplify a special form of memory and consciousness called autonoetic consciousness (Tulving, 2005) or explicit memory (Graf and Schacter, 1985). Facts that are judged to be only known are thought to require only semantic knowledge or mere familiarity and are thought to require only primed noetic consciousness or implicit memory.

There have been many debates over the past decade about this distinction. People question whether it means that there are different systems of memory, or whether it might be due only to differences in the amount of information stored (e.g., with better-stored memories being judged as remembered and less well-stored memories being judged as merely known). One larger issue here is to whether the phenomenology of recollecting actually contributes to one's recognizing something as being previously studied versus whether this phenomenology is merely epiphenomenal; you have the experience of recollecting (e.g., that you recalled Denver Broncos when football had been presented), but this experience does not contribute to your ability to correctly recognize an item as previously studied. Advocates of dual-process models of recognition – which indicate that both familiarity and recollection influence recognition decisions – state that recollection has a causal influence on our recognition performance, whereas strength theorists claim that a single underlying memory dimension (e.g., familiarity alone) can adequately explain recognition. For the latter group, recollections merely arise from having strong memories, but the phenomenology itself is not important for understanding recognition *per se* (for competing views, see Yonelinas, 1994; Rottello et al., 2005).

Paradigms involving this distinction purportedly allow us to ascertain whether people are consciously aware of the memories. This particular metacognitive judgment, then, is one that has been extensively researched and debated. A detailed discussion of the remember/know literature is given in a separate chapter of this handbook, and so we do not elaborate further on it here. We include this section only to note that this particular judgment, like all of those outlined above, is a kind of metacognition because it involves an attribution about a memory, though one that may have considerable consequence for understanding human memory and consciousness.

## 2.20.2 Conclusion

Much progress has been made in understanding the mechanisms that underlie the judgments that people can make about their memories. There is considerable agreement that metacognitive judgments are heuristically based. People seem to rely on the information that they have at hand, and usually on a fairly shallow assessment of that information, to make these judgments. Because these judgments are heuristically based, systematic biases are observed. Under some circumstances, people will be underconfident or overconfident; in other situations, they can be misled. However, insofar as research is untangling those systematic biases and the reasons for them, we are increasingly in a position to help students improve their metacognitions, and hence base their learning on a firmer foundation.

## References

Begg I, Duft S, Lalonde P, Melnick R, and Sanvito J (1989) Memory predictions are based on ease of processing. *J. Mem. Lang.* 28: 610–632.

Benjamin AS (2005) Response speeding mediates the contribution of cue familiarity and target retrievability to metamnemonic judgments. *Psychon. Bull. Rev.* 12: 874–879.

Benjamin AS, Bjork RA, and Schwartz BL (1998) The mismeasure of memory: When retrieval fluency is misleading as a metamnemonic index. *J. Exp. Psychol. Gen.* 127: 55–68.

Bjork RA (1994) Memory and metamemory considerations in the training of human beings. In: Metcalfe J and Shimamura A (eds.) *Metacognition: Knowing About Knowing*, pp. 185–206. Cambridge, MA: MIT Press.

Burke DM, MacKay DG, Worthley JS, and Wade E (1991) On the tip of the tongue: What causes word finding failures in young and older adults? *J. Mem. Lang.* 30: 542–579.

Dunlosky J and Connor L (1997) Age-related differences in the allocation of study time account for age-related differences in memory performance. *Mem. Cognit.* 25: 691–700.

Dunlosky J and Hertzog C (2000) Updating knowledge about strategy effectiveness: A componential analysis of learning about strategy effectiveness from task experience. *Psychol. Aging* 15: 462–474.

Dunlosky J and Matvey G (2001) Empirical analysis of the intrinsic-extrinsic distinction of judgments of learning

(JOLs): Effects of relatedness and serial position on JOLs. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 1180–1191.
Dunlosky J and Nelson TO (1997) Similarity between the cue for judgments of learning (JOL) and the cue for test is not the primary determinant of JOL accuracy. *J. Mem. Lang.* 36: 34–49.
Dunlosky J and Serra M (2006) Is the influence of test trials on judgments of learning analytic? Poster presented at the 47th Meeting of the Psychonomics Society. Houston, TX.
Dunlosky J, Hertzog C, Kennedy MRT, and Thiede KW (2005a) The self-monitoring approach for effective learning. *Cogn. Technol.* 10: 4–11.
Dunlosky J, Rawson KA, and Middleton E (2005b) What constrains the accuracy of metacomprehension judgments? Testing the transfer-appropriate-monitoring and accessibility hypotheses. *J. Mem. Lang.* 52: 551–565.
Eakin DK (2005) Illusions of knowing: Metamemory and memory under conditions of retroactive interference. *J. Mem. Lang.* 52: 526–534.
Ferguson SA, Hashtroudi S, and Johnson MK (1992) Age differences in using source-relevant cues. *Psychol. Aging* 7: 443–352.
Finn B and Metcalfe J (2007) The role of memory for past test in the underconfidence with practice effect. *J. Exp. Psychol. Learn. Mem. Cogn.* 33(1): 238–244.
Finn B and Metcalfe J (2008) Judgments of learning are influenced by memory for past test. *J. Mem. Lang.* 58: 19–34.
Glenberg AM and Epstein W (1987) Inexpert calibration of comprehension. *Mem. Cogn.* 15: 84–93.
Graf P and Shacter DL (1985) Implicit and explicit memory for new associations in normal and amnesic subjects. *J. Exp. Psychol. Learn. Mem. Cogn.* 11: 501–508.
Hertzog C, Dunlosky J, Robinson AE, and Kidder DP (2003) Encoding fluency is a cue used for judgments about learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 22–34.
James LE and Burke DM (2000) Phonological priming effects on word retrieval and tip-of-the-tongue experiences in young and older adults. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1378–1391.
James W (1890/1981) *The Principles of Psychology*, vol. 1. New York: Henry Holt and Co.
Jang Y, Huber DE, and Wallsten TS (2006) Judgments of learning: Beyond gamma. Poster presented at the 47th Meeting of the Psychonomics Society. Houston, TX.
Johnson MK (1983) A multiple-entry, modular memory system. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 17, pp. 81–123. New York: Academic Press.
Johnson MK and Mitchell KJ (2002) Source monitoring. In: *Macmillan Psychology Reference Series Volume 2: Learning and Memory*, 2nd edn., pp. 628–631. New York: Macmillan Reference.
Johnson MK and Raye LC (1981) Reality monitoring. *Psychol. Rev.* 88: 67–85.
Johnson MK, Raye CL, Wang AY, and Taylor TH (1979) Fact and fantasy: The roles of accuracy and variability in confusing imaginations with perceptual experiences. *J. Exp. Psychol. Hum. Learn. Mem.* 5(3): 229–240.
Johnson MK, Hashtroudi S, and Lindsay DS (1993) Source monitoring. *Psychol. Bull.* 114: 3–28.
Jones GV (1989) Back to Woodworth: Role of interlopers in the tip of the tongue phenomenon. *Mem. Cognit.* 17: 69–76.
Kelley CM and Muller KA (2006) Sources of the underconfidence-with-practice effect. Paper presented at the 47th Meeting of the Psychonomics Society. Houston, TX.
Kimball DR and Metcalfe J (2003) Delaying judgments of learning affects memory, not metamemory. *Mem. Cognit.* 31: 918–929.
King JF, Zechmeister EB, and Shaughnessy JJ (1980) Judgments of knowing: The influence of retrieval practice. *Am. J. Psychol.* 93: 329–343.
Koriat A (1993) How do we know that we know? The accessibility model of the feeling of knowing. *Psychol. Rev.* 100: 609–639.
Koriat A (1997) Monitoring one's knowledge during study: A cue-utilization approach to judgments of learning. *J. Exp. Psychol. Gen.* 126: 349–370.
Koriat A (2000) The feeling of knowing: Some metatheoretical implications for consciousness and control. *Conscious. Cognit.* 9: 149–171.
Koriat A and Goldsmith M (1996) Monitoring and control processes in the strategic regulation of memory accuracy. *Psychol. Rev.* 103: 490–517.
Koriat A and Levy-Sadot R (2001) The combined contributions of the cue-familiarity and accessibility heuristics to feelings of knowing. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 34–53.
Koriat A and Ma'ayan H (2005) The effects of encoding fluency and retrieval fluency on judgments of learning. *J. Mem. Lang.* 52: 478–492.
Koriat A, Sheffer L, and Ma'ayan H (2002) Comparing objective and subjective learning curves: Judgments of learning exhibit increased underconfidence with practice. *J. Exp. Psychol. Gen.* 131(2): 147–162.
Koriat A, Ma'ayan H, Sheffer L, and Bjork RA (2006) Exploring a mnemonic debiasing account of the underconfidence-with-practice effect. *J. Exp. Psychol. Learn. Mem. Cogn.* 32(3): 595–608.
Kornell N and Metcalfe J (2007) ''Blockers'' Do Not Block Recall During Tip-of-the-Tongue States. *Metacogn. Learn.* 1: 248–261.
Leibert TW and Nelson DL (1998) The roles of cue and target familiarity in making feeling of knowing judgments. *Am. J. Psychol.* 111: 63–75.
Lichtenstein S and Fischhoff B (1977) Do those who know more also know more about how much they know? *Org. Behav. Hum. Perform.* 20: 159–183.
Maki RH (1999) The roles of competition, target accessibility, and cue familiarity in metamemory for word pairs. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 1011–1023.
Matvey G, Dunlosky J, and Schwartz B (2006) The effects of categorical relatedness on judgments of learning (JOLs). *Memory* 14: 253–261.
Mayer RE (1995) The search for insight: Grappling with Gestalt psychology's unanswered questions. In: Sternberg RJ and Davidson JE (eds.) *The Nature of Insight*, pp. 3–32. Cambridge, MA: MIT Press.
Mazzoni G and Cornoldi C (1993) Strategies in study-time allocation: Why is study time sometimes not effective? *J. Exp. Psychol. Gen.* 122: 47–60.
Meeter M and Nelson TO (2003) Multiple study trials and judgments of learning. *Acta Psychol.* 113: 123–132.
Metcalfe J (2000) Feelings and judgments of knowing: Is there a special noetic state? *Conscious. Cogn.* 9: 178–186.
Metcalfe J, Schwartz BL, and Joaquim SG (1993) The cue-familiarity heuristic in metacognition. *J. Exp. Psychol. Learn. Mem. Cogn.* 19: 851–861.
Metcalfe J, Funnell M, and Gazzaniga MS (1995) Right-hemisphere memory superiority: Studies of a split brain patient. *Psychol. Sci.* 6(3): 157–164.
Miner AC and Reder LM (1994) A new look at feeling of knowing: Its metacognitive role in regulating question answering. In: Metcalfe J and Shimamura A (eds.) *Metacognition: Knowing About Knowing*, pp. 47–70. Cambridge, MA: MIT Press.
Mitchell KJ and Johnson MK (2000) Source monitoring: Attributing mental experiences. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 179–196. New York: Oxford University Press.
Nelson TO and Dunlosky J (1991) When people's judgments of learning (JOLs) are extremely accurate at predicting

subsequent recall: The "delayed-JOL effect." *Psychol. Sci.* 2: 267–270.
Nelson TO and Narens L (1990) Metamemory: A theoretical framework and new findings. In: Bower GH (ed.) *The Psychology of Learning and Motivation,* vol. 26, pp. 125–173. New York: Academic Press.
Nelson TO and Narens L (1994) Why investigate metacognition? In: Metcalfe J and Shimamura AP (eds.) *Metacognition: Knowing About Knowing*, pp. 1–25. Cambridge, MA: MIT Press.
Nelson TO, Narens L, and Dunlosky J (2004) A revised methodology for research on metamemory: Pre-judgment recall and monitoring (PRAM). *Psychol. Meth.* 9: 53–69.
Reason JT and Lucas D (1984) Using cognitive diaries to investigate naturally occurring memory blocks. In: Harris J and Morris PE (eds.) *Everyday Memory, Actions, and Absent-Mindedness*, pp. 53–70. London: Academic Press.
Reder L (1987) Strategy selection in question answering. *Cognit. Psychol.* 19: 90–138.
Reder LM and Ritter FE (1992) What determines initial feeling of knowing? Familiarity with question terms, not with the answer. *J. Exp. Psycholo. Learn. Mem. Cogn.* 18: 435–451.
Rotello CM, Macmillan NA, Reeder JA, and Wong M (2005) The remember response: Subject to bias, graded, and not a process-pure indicator of recollection. *Psychon. Bull. Rev.* 12: 865–873.
Scheck P and Nelson TO (2005) Lack of pervasiveness of the underconfidence-with-practice effect: Boundary conditions and an explanation via anchoring. *J. Exp. Psychol. Gen.* 134: 124–128.
Schwartz BL (1999) Sparkling at the end of the tongue: The etiology of tip-of-the-tongue phenomenology. *Psychon. Bull. Rev.* 6: 379–393.
Schwartz BL (2002) *Tip-of-the-Tongue States: Phenomenology, Mechanism, and Lexical Retrieval*. Mahwah, NJ: Erlbaum.
Schwartz BL (2006) Tip-of-the-tongue states as metacognition. *Metacogn. Learn.* 1: 149–158.
Schwartz BL and Frazier LD (2005) Tip-of-the-tongue states and aging: Contrasting psycholinguistic and metacognitive perspectives. *J. Gen. Psychol.* 132: 377–391.
Serra MJ and Dunlosky J (2005) Does retrieval fluency contribute to the underconfidence-with-practice effect? *J. Exp. Psycholo. Learn. Mem. Cogn.* 31: 1258–1266.
Sikstrom S and Jonsson F (2005) A model for stochastic drift in memory strength to account for judgments of learning. *Psychol. Rev.* 112(4): 932–950.
Son LK and Metcalfe J (2000) Metacognitive and control strategies in study-time allocation. *J. Exp. Psycholo. Learn. Mem. Cogn.* 26: 204–221.
Son LK and Metcalfe J (2005) Judgments of Learning: Evidence for a Two-Stage Model. *Mem. Cognit.* 33: 1116–1129.
Spellman BA and Bjork RA (1992) Technical commentary: When predictions create reality: Judgments of learning may alter what they are intended to assess. *Psychol. Sci.* 3: 315–316.
Terrace HS and Metcalfe J (2005) *The Missing Link in Cognition: Origins of Self-Reflective Consciousness*. New York: Oxford University Press.
Thiede KW and Dunlosky J (1999) Toward a general model of self-regulated study: An analysis of selection of items for study and self-paced study time. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 1024–1037.
Thiede KW, Anderson MCM, and Therriault D (2003) Accuracy of metacognitive monitoring affects learning of texts. *J. Educ. Psychol.* 95: 66–73.
Tulving E (2005) Episodic memory and autonoesis: uniquely human? In: Terrace HS and Metcalfe J (eds.) *The Missing Link in Cognition: Origins of Self-Reflective Consciousness*, pp. 3–56. Oxford: Oxford University Press.
Weaver C and Kelemen WL (2003) Processing similarity does not improve metamemory: Evidence against transfer-appropriate monitoring. *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 1058–1065.
Yonelinas AP (1994) Receiver-operating characteristics in recognition memory: Evidence for a dual-process model. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 1341–1354.

# 2.21 Déjà Vu

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The déjà vu phenomenon is one of the most intriguing illusions of memory. We automatically monitor the familiarity of experiences and surroundings. Nearly always, our subjective sense of familiarity corresponds to objective reality, but on rare occasions these clash, giving rise to a feeling of familiarity in the absence of objective evidence.

> We are in a strange place, perhaps on holiday for the first time at a hotel. Suddenly, without warning, a certain feeling of familiarity seems to create itself. At once we seem to know the whole scene, windows, doors, pictures, and view from the windows. We recognize the person with whom we are speaking, although . . . we have never seen him to this minute. We even recognize the words he is saying, though it is impossible to know what he is going to say. We have the feeling of having been through everything before! Then, in a flash, the illusion vanishes. (Humphrey, 1923: 137)

The standard definition for déjà vu, presented by Neppe (1983b: 3), is "any subjectively inappropriate impression of familiarity of a present experience with an undefined past" and a more recent reformulation that incorporates cognitive terminology is "an objective assessment of unfamiliarity juxtaposed with a subjective evaluation of familiarity" (Brown, 2003: 2).

## 2.21.1 Challenges of Déjà Vu Research

The literature on déjà vu extends back over 150 years, and interest in the phenomenon encompasses a wide range of disciplines from medicine to philosophy to psychology (Brown, 2004). Despite this plethora of attention, the phenomenon of déjà vu has struggled to make a solid connection with empirical research in psychology. Although some twentieth-century researchers studied memory errors (e.g., Bartlett, 1932), most followed the lead of Ebbinghaus (1885), where memory errors were ignored or controlled rather than examined as worthy phenomena in their own right (cf. Roediger, 1996). There has been a change over the past few decades, and cognitive scientists have begun to explore the relationship of the déjà vu experience to phenomena such as repetition priming (Schacter, 1996), source attribution (Hoffman, 1997), perceptual fluency (Jacoby and Whitehouse, 1989; Bernstein and Welch, 1991; Joordens and

Merikle, 1992; Roediger, 1996), and subliminal mere exposure (Seamon et al., 1983).

What makes research on déjà vu problematic is the lack of any clearly identifiable eliciting stimulus and objective behaviors. Not only have the causes been elusive; an objective observer may find it impossible to determine whether someone is experiencing déjà vu. Other cognitive phenomena, such as the tip-of-the-tongue experience (Brown, 1991; also *see* Chapter 2.22), have a clear stimulus (John Kerry's vice presidential running mate in 2000) and behavioral resolution (John Edwards). However, reports of déjà vu experiences rely on one's sensitivity to, and awareness of, their own cognitive functioning.

## 2.21.2 Defining Déjà Vu

Through the mid-1900s, researchers used over 30 different words and phrases to describe déjà vu (see Brown, 2004), including such colorful expressions as paramnesia (Burnham, 1889), diplopia (Taylor, 1931), perplexity psychosis (MacCurdy, 1925), promnesia (Myers, 1895), and prescience (Crichton-Browne, 1895). This diversity of terms reflects several things about the experience. First, it is inexplicable and difficult to construct a word or short phrase to appropriately label it. Second, developing a reasonable definition of the subjective experience has been problematic. Brown (2004) assembled over 50 different definitions that reflect this hegemony. Third, there is a lack of consensus among researchers and writers on the cause: Is it a physiological, memory, or perceptual problem? This diversity hampered early research, and settling on the common French language term was accompanied by considerable struggle and debate (Marková and Berrios, 2000).

## 2.21.3 Methods of Investigating Déjà Vu

The primary method for studying déjà vu has been retrospective questionnaire, usually involving either a brief inquiry about the incidence of déjà vu or a more extensive assessment of multiple dimensions of the déjà vu experience (setting, duration, etc.). The most significant problem with retrospective surveys of déjà vu stems from the rarity of the experience (Adachi et al., 2003). Given that most people who do have déjà vu only experience it one to two times per year, it poses a serious challenge to remember the details of an experience that probably happened many months ago, and in ordinary circumstances that may not be very memorable. Thus, survey data provide a conservative estimate, at best, of the actual frequency of déjà vu. Biases also exist in the sampling of respondents (cf. Brown, 2004), with many surveys based on a selection of individuals that are conveniently available (college students for research professors; hospital patients for research physicians).

### 2.21.3.1 Unfortunate Association with the Paranormal and Abnormal

A serious problem with déjà vu assessments is that about one-third of surveys imbed their déjà vu item among items inquiring about paranormal (extrasensory perception, haunting, poltergeist, unidentified flying object) phenomena (cf. Brown, 2004). Other questionnaires imply a relationship between déjà vu and dimensions of psychopathology such as agoraphobia, depersonalization, and derealization (Buck and Geers, 1967; Harper, 1969; Harper and Roth, 1962; Brauer et al., 1970; Buck, 1970; Myers and Grant, 1972). Thus, respondents are given the message that déjà vu is inherently abnormal, which may reduce the willingness of individuals to admit to having such experiences.

### 2.21.3.2 Prospective Surveys

A prospective survey can solve the memory problem inherent in retrospective surveys. However, only Heymans (1904, 1906; translated by Sno and Draaisma, 1993) has employed such a technique, and the lack of methodological clarity coupled with the disparity of incidence estimates in two separate samples (14% vs. 62%; see Brown, 2004) make these data difficult to interpret. One other published prospective report is a case study. Leeds (1944) experienced an extraordinarily high rate of déjà vu (once every 2–3 days), which motivated him to keep a remarkably detailed record of 144 of his own déjà vu experiences, including date, time, intensity, duration, physical setting, and his behaviors, as well as his psychological and physical state at the time. He discovered that the intensity and duration of the experiences were directly related, that longer inter-episode intervals resulted in more intense and longer experiences. Leeds further observed that déjà vu experiences come in clusters and occasionally occur in dreams. His record is fascinating in its remarkable detail, although these experiences may reflect pathological rather than normal déjà vu.

## 2.21.4 Incidence of Déjà Vu

Based on numerous surveys, déjà vu may not be a universal experience. Given this, it is important to separately examine two different dimensions – the incidence of the illusion and how often it occurs among those who have ever experienced it (experients). Across 57 outcomes from 42 published studies, Brown (2004) found that déjà vu is experienced by about two-thirds of those surveyed. The incidence varies considerably across surveys – ranging from 10–100% – and several factors account for this extreme variability. The item context within which the query is placed probably has a substantial impact. As noted earlier, when the déjà vu item accompanies items on paranormal phenomena, this most likely suppresses the reported incidence. The cultural acceptability and understanding of the experience has increased across time (cf. Brown, 2004), so more recent surveys tend to show a higher incidence. Finally, the age of the sample influences the incidence, and samples of older participants tend to show a lower incidence (cf. Brown, 2003).

How often does déjà vu occur among experients? Surveys suggest that it is not a singular event, with the vast majority of experients having more than one lifetime déjà vu (Palmer 1979; Kohr, 1980). About half of experients have had seven or more occurrences in their lifetime (Kohr, 1980). Using a Likert scale, around half of respondents rate déjà vu occurrences as 'seldom' (Leeds, 1944; NORC, 1984, 1988, 1989; McCready and Greeley, 1976), with a relatively small percentage (between 9% and 18%) rating it as 'frequent.' Data derived from more recent surveys indicate that déjà vu appears to occur at least once a month for most experients (Ardilla et al., 1993; Brown et al., 1994; Roberts et al., 1990).

## 2.21.5 Nature of the Déjà Vu Experience

### 2.21.5.1 What Triggers Déjà Vu?

Brown et al. (1994) discovered that the most important element in eliciting déjà vu is the general physical setting, with over half (54%) of experients claiming that this was always the cause (see Neppe, 1983b). Spoken words, actions, and objects are also noted as contributing to the déjà vu experience, although to a far lesser extent. Stress is mentioned in many anecdotal reports as a causative factor in déjà vu (see Brown, 2004), although Brown et al. (1994) found that only a small fraction of open-ended survey responses (about 20%) contained any such reference. The vast majority (three-quarters) of déjà vu experiences occur indoors, about evenly distributed between private and public buildings. Furthermore, about half of déjà vu experiences occur when one is engaged in recreational activities. Déjà vu rarely happens when one is alone and most typically occurs while in the company of one other person (usually a friend).

The déjà vu experience is relatively brief, with about half of survey respondents reporting that it lasts less than 5 s. Déjà vu is more likely to occur during the afternoon or evening (Heymans, 1904; Leeds, 1944) and late in the week (Thursday through Saturday) (Brown, 2004), and the sense of time seems to be momentarily slowed for many experients. It is difficult to precisely identify the emotional reaction accompanying déjà vu. Some characterize this as an essential part of the experience, but the most predominant reactions appear to have more of cognitive than emotional flavor (Brown, 2004), with those surveyed most often describing it as eerie, surprising, odd, confusing, exciting, and curious.

## 2.21.6 Physical and Psychological Variables Related to Déjà Vu

The most consistent finding in the déjà vu literature is that the incidence systematically decreases with age from the 20s through the 80s (Brown, 2003, 2004), although teenagers tend to experience déjà vu less often than those in their 20s. Data on changes across broad age ranges are found in two studies with hospital patients (Chapman and Mensh, 1951; Richardson and Winokur, 1968). A larger sample with a more representative cross section of individuals was conducted by the National Opinion Research Center (NORC) in their General Social Surveys conducted in 1984, 1988, and 1989. The data from these sources are summarized in **Figure 1**, and all three sources confirm the systematic decline in the incidence of déjà vu with age. In addition, significant negative correlations have been found between age and déjà vu experience, ranging from −.22 to −.38 (Chapman and Mensh, 1951; Kohr, 1980; NORC, 1984, 1988, 1989; Sno et al., 1994; Adachi et al., 2003). Given that older adults used to be young, the lifetime incidence of déjà vu should either remain steady or increase, rather than drop. However, this logically impossible age change is probably due to an increase

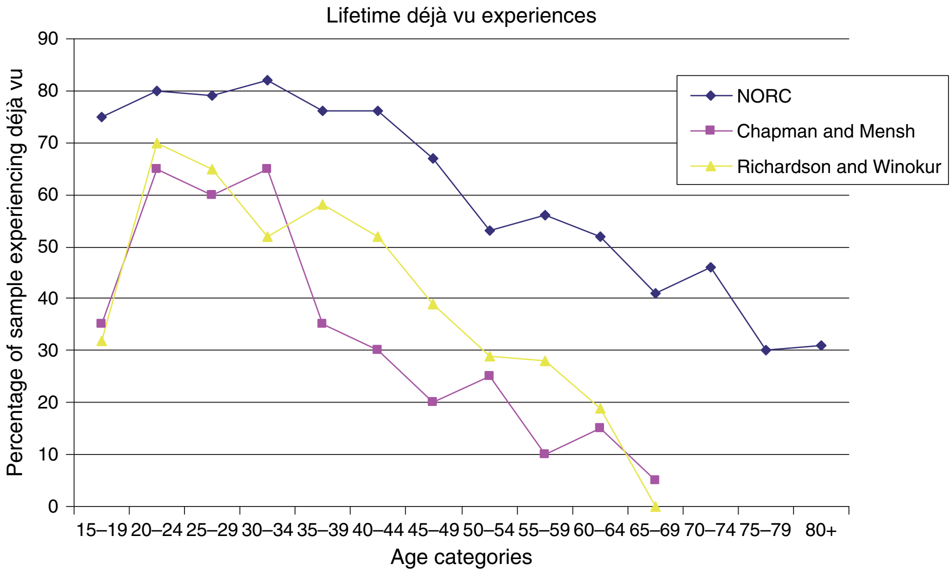


**Figure 1** Percent of respondents experiencing déjà vu across age groups (from three surveys).

in the cultural awareness and acceptability of the experience across the past four or five decades (Brown, 2004).

Among experients, the incidence of déjà vu drops off dramatically across the adult age span (Chapman and Mensh, 1951; Richardson and Winokur, 1968), as reflected in **Figure 2**. Why do older experients report fewer incidents of déjà vu? Perhaps they are less in touch with the subtle qualities of their own cognitive experiences (Brown et al., 1995), are more settled in their physical routine and less likely to encounter new experiences to trigger déjà vu, or have a greater acceptance of incongruent memory experiences (Adachi et al., 2003). There has been no extensive survey on the minimum age at which déjà vu first occurs, although Neppe (1983b) discovered that some adults claim to have had their first déjà vu sometime in the teens or 20s. Fukuda (2002) found a

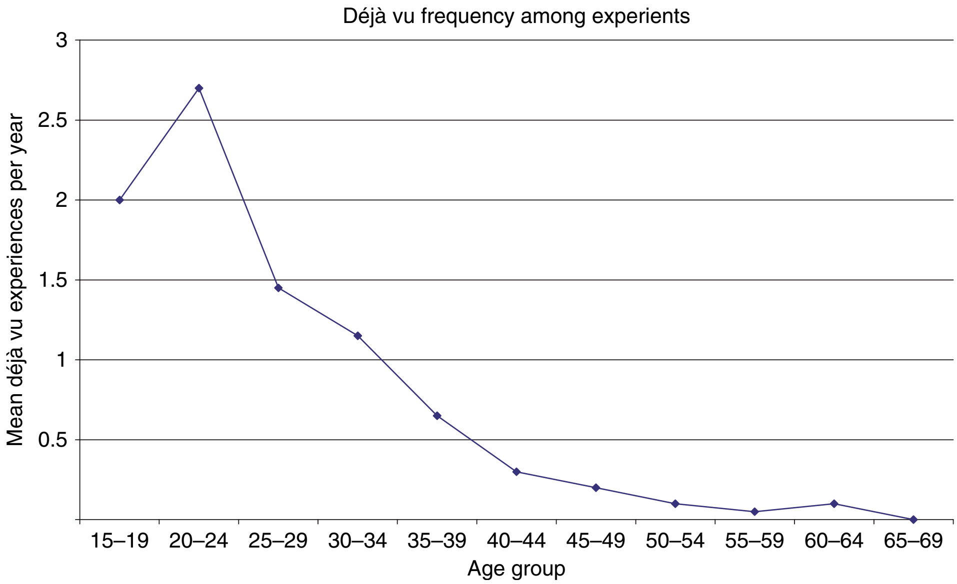


**Figure 2** Yearly frequency of déjà vu across age groups among those who have the experience.

somewhat earlier estimate in a retrospective survey of college students, with most claiming a first experience between ages 6 and 10 (49%) or between ages 11 and 15 (33%).

There is a positive relationship between déjà vu incidence and education (Chapman and Mensh, 1951; Richardson and Winokur, 1967, 1968; Harper, 1969; Palmer, 1979; Kohr, 1980; Neppe, 1983b; NORC, 1984, 1988, 1989; Gallup and Newport, 1991; Adachi et al., 2003) and between déjà vu and travel frequency (Brown, 2004). Déjà vu incidence appears to be directly related to socioeconomic status (SES) (Crichton-Browne, 1895; Chapman and Mensh, 1951; Richardson and Winokur, 1967, 1968; Harper, 1969; Palmer, 1979; Gallup and Newport, 1991). Because socioeconomic status and academic achievement are closely intertwined, Brown (2004) attempted to extricate the separate contributions of each variable by comparing low versus high SES within each of four education levels within the NORC survey database. Déjà vu incidence was higher for low than for high SES within each education level, although the incidence systematically increased with each level of education. Thus, SES and education level are associated with déjà vu experience in opposite ways: Déjà vu is inversely related to SES but directly related to education level. Travel also appears to be associated with déjà vu. Those who do any travel are more likely to report déjà vu than those who don't, with little difference across various numbers of trips (Brown, 2004). Déjà vu incidence is unrelated to gender, race (black vs. white), religious preferences, or political affiliation (Brown, 2003, 2004), although there is a clear tendency for déjà vu incidence to be higher among those with a liberal versus conservative orientation.

There is some evidence that various prescription and nonprescription drugs have the potential to either trigger (amphetamines, Ellinwood, 1968; carbamazepine and clonazepam, Garbutt and Gillette, 1988; toluene, Takaoka et al., 2001; amantadine hydrochloride and phenylpropanolamine hydrochloride, Taiminen and Jääskeläinen, 2001) or reduce (clonazepam, Ide et al., 2000) déjà vu experiences, but this is based on selective data from case reports. There appears to be a tendency for déjà vu to be elevated in alcoholics (Turner, 1910), and NORC data reveal a positive association between alcohol consumption and déjà vu, with those who drink experiencing it more frequently than those who don't.

## 2.21.7 Physiopathology and Déjà Vu

Some of the early explorations of déjà vu were motivated by an apparent association between temporal lobe epilepsy (TLE) and déjà vu (Quaerens, 1870; Jackson, 1888; Maudsley, 1889; Crichton-Browne, 1895). A small percentage of TLEs experience déjà vu in the aura that immediately precedes their seizure, and one physician documented his personal experiences in a published report, claiming that his first epileptic attack was preceded by a series of increasingly frequent and intense déjà vu experiences (Quaerens, 1870). This issue has been debated for many decades, but most evidence suggests that déjà vu is not symptom or cause specific to epilepsy (Richardson and Winocur, 1967; Harper, 1969). However, research conducted on TLEs has contributed to our understanding of the experience. An examination of cortical activity in TLEs with both electrical stimulation and recording procedures (Mullan and Penfield, 1959; Cole and Zangwill, 1963; Penfield and Perot, 1963; Penfield and Mathieson, 1974; Gupta et al., 1983; Cutting and Silzer, 1990; Gloor, 1991; Palmini and Gloor, 1992; Fish et al., 1993; Weinand et al., 1994; Sengoku et al., 1997; Adachi et al., 1999) suggests that déjà vu is associated with activity in the right temporal lobe, specifically involving the hippocampus and areas immediately surrounding it (e.g., amygdala, parahippocampal gyrus, temporal isocortex) (although see Brown, 2004, for cautions in interpreting these data).

Some evidence suggests that déjà vu may be more common in those who have suffered head trauma, especially accompanied by amnesia (Weinstein et al., 1962) or disturbance/loss of consciousness (Harper, 1969; Weinstein, 1969). It has been suggested that déjà vu is associated with various moderate to severe psychological disturbances (Calkins, 1916; Pickford, 1944) such as schizophrenia (Neppe, 1983b; Sno et al., 1992; Sno, 2000), but there has been no definitive verification that déjà vu is associated with any form of psychopathology (Brown, 2004). There is, however, modest evidence that déjà vu may be associated with depersonalization and derealization (Roth, 1959; Buck and Geers, 1967; Harper, 1969; Myers and Grant, 1972), but others have failed to find support for such an association (Brauer et al., 1970; Dixon, 1971; Adachi et al., 2003). Some have argued that déjà vu should be included in the *Diagnostic and Statistical Manual* (DSM) of the American Psychiatric Association as a form of psychopathology (Sno and Linszen, 1990; Sno et al., 1992), although this change has not garnered broad support (cf. Pagliaro, 1991).

## 2.21.8 Interpretations of Déjà Vu

Researchers have proposed over 40 different explanations for déjà vu (Brown, 2004), and Neppe (1983a: 33) cogently suggests that " . . . one single explanation for déjà vu is probably as untrue as one single cause for headache." Belief in the existence of parapsychological phenomena (mental telepathy, precognition, reincarnation) may have roots in déjà vu (Stern, 1938; Carmichael, 1957), given that it is a common experience that can easily feel supernatural. There has also been a considerable amount of published speculation about the psychodynamic underpinnings of déjà vu, suggesting that an individual attempts to subconsciously reduce situational anxiety by labeling it as 'familiar' (see Arlow, 1959). These two classes of interpretations will not be covered in this chapter, but the interested reader is directed to summaries found in Brown (2004).

## 2.21.9 Dual-Processing Explanations

Four different categories of scientifically oriented explanations of déjà vu are described in Brown (2004). Of these, the dual-processing explanations are perhaps more philosophical than scientific, yet draw on established cognitive phenomena. Each variety of explanation in this category assumes that two routine cognitive processes are momentarily out of normal synchrony with each other. For instance, retrieval and familiarity usually work jointly and in close coordination – when one recalls information it is accompanied by an assessment of familiarity. However, if familiarity assessment becomes activated spuriously and independently of recall, a situation may be incorrectly assessed as previously experienced when it was not (Claparède, 1951; Gloor, 1991). Similarly, if encoding and retrieval, which normally operate separately, are activated simultaneously, this could result in a misimpression that the present (new) experience has been retrieved from memory (de Nayer, 1979). Along similar lines, déjà vu has been interpreted as involving the merging of perception and encoding processes (Carrington, 1931), perception and retrieval (Ellis, 1911), implicit and explicit information processing (Wigan, 1844; Myers, 1895), and different states of conscious awareness (Jackson, 1888). Although all of these are logically engaging and theoretically possible, they do not readily lend themselves to empirical evaluation. In the following sections are three categories of déjà vu explanations that provide a more solid scientific foundation on which to evaluate the possible cause(s) of déjà vu.

## 2.21.10 Neurological Explanations

Déjà vu may result from a minimal biological dysfunction involving cortical information processing. This interpretation has its roots in the observation that some TLEs experience déjà vu prior to their seizure (see earlier section titled 'Physiopathology and déjà vu'). If a minor neurological misfiring, or small seizure, occurs in individuals without brain pathology, then this could possibly trigger déjà vu (Halgren et al., 1978; Bancaud et al., 1994). Elaborating on this concept, Spatt (2002) speculated that spontaneous activity in the parahippocampal area of the cerebral cortex, a region routinely involved in encoding and retrieval activities, could create a brief sense of inordinate familiarity that is disconnected from one's present objective experience.

A second variety of neurological explanation assumes that a brief and minimal change in the speed of neural transmission could create an illusion of 'pastness.' Our nervous system transmits the perceptual information we receive in a highly reliable and consistent fashion. Imagine, however, that this tightly formatted neural transmission is momentarily altered by an aberrant event – say, a deficiency or excess of a neurotransmitter at a particular synaptic juncture. This retarding (Grasset, 1904) or acceleration (Allin, 1896) of the message may be misinterpreted as inordinate familiarity (cf. Jacoby, 1988; Jacoby et al., 1988) with an objectively new experience (Burnham, 1889; Ellis, 1911; Schacter, 2001).

Extending this speculation, if two perceptual pathways are involved, any temporal disparity would be even more pronounced. It has been demonstrated that perceptual information is transmitted to cortical processing centers via multiple pathways (Schneider, 1969; Goodale and Milner, 1992; Milner and Goodale, 1995). Imagine that a slight interruption occurs to one of these two messages, but not the other. An additional separation of only a few extra milliseconds between the duplicate messages may create a perceptual echo sufficient to flummox the interpretive centers of the cortex and lead to a misimpression that the second (delayed) perceptual event duplicates the first (leading) message. This possibility was proposed over a century ago and has been elaborated on and extended by many others since (Wigan, 1844; Osborn, 1884; Maudsley, 1889; Myers, 1895; Humphrey, 1923; Efron, 1963; Weinand et al., 1994). Some of the early versions of this dual-message interpretation were grounded in a communication problem between hemispheres and disparities regarding the timing of this information exchange (Wigan, 1844; Myers, 1895; Humphrey, 1923).

A frequently reported feature accompanying personal reports of déjà vu is a sense of precognition (cf. Brown, 2004), with an individual believing that they know exactly what is going to happen moments before it does. On the surface, this appears to challenge any scientific explanation of déjà vu. However, a neurological interpretation involving dual pathways may help explicate this unusual subjective experience. When an inordinate separation occurs between two neural messages, the brain could theoretically focus primarily on either the leading or the trailing version. If the trailing perception is central, then a sense of déjà vu results because the first message already arrived. In contrast, if the brain invests in the leading message, then a sense of precognition could result because the individual can literally foresee what will happen moments later via this brief preview (Efron, 1963; Kohn, 1983).

## 2.21.11 Implicit Memory Explanations

A déjà vu experience may result from an implicit memory for one or more aspects of the present situation (Schacter, 1987; Richardson-Klavehn and Bjork, 1988; Roediger and McDermott, 1993). When the present setting cues an implicit memory that is missing an associated episodic component, one could experience a sense of familiarity that is missing the recollective dimension. The simplest form of this interpretation is that our entire present experience duplicates something encountered earlier (Chapman and Mensh, 1951). Abercrombie (1836) and Osborn (1884) present case reports of déjà vu experiences in adulthood that were later traced to actual childhood events. Abercrombie (1836) described a woman who had a déjà vu experience when escorted to the room where her mother had died. She had no conscious recollection of having been there before, but found out later that as an infant she had been taken to visit her dying mother there. Osborn (1884) discussed a similar incident, where a man experienced a déjà vu at a castle entrance, only to find out later that he had visited that very location with his parents when he was one and a half years old.

Literary works also have the capacity to implant in memory detailed descriptions of scenes or settings that subsequently provide a striking fit to real experience (Hawthorne, 1863; Knight, 1895). Media exposure (television, movies, magazines) also has the potential to paint vivid mental images that can connect to subsequent real experiences, without a recollection of the source. Ellis (1897, 1911) described a déjà vu in a particular setting that he later traced back to a stereoscope picture that he had seen of that exact location. The Internet now provides a particularly rich set of images of real locations. In fact, a television ad by Hotels.com humorously highlights this possibility: A man walks into a room and breathlessly exclaims, 'I've been here before,' to which his partner replies that he saw it in a Web video preview prior to reserving the room online.

Rather than duplicating the entire previous experience, Osborn (1884) speculated that déjà vu may result if the manner in which the information is processed duplicates the way that a previous experience was processed (Kolers, 1973; Morris et al., 1977; Kolers and Roediger, 1984). Although more difficult to test, this processing duplication could allow a much broader generalization of familiarity from one setting to another. Also, the duplication could involve the general perceptual form of some visual or auditory event from our past (Grasset, 1904; Reed, 1974). This gestalt familiarity interpretation is deftly illustrated by Dashiell (1937) in his textbook on psychology (see **Figure 3**). He suggested that if an individual encounters setting A that is new, this may evoke a déjà vu due to its resemblance to the general form of setting B that is familiar. None of the individual elements are identical across settings, but the overall form of the new street scene strongly resembles the familiar scene – large building close on the right side of the street, a church with steeple down the left side of the street, and so forth.

Rather than duplicating the entire prior experience or its general form, perhaps one element in the present experience is old but not identified as such. This element elicits a strong familiarity response that we fail to attach to it, and so we

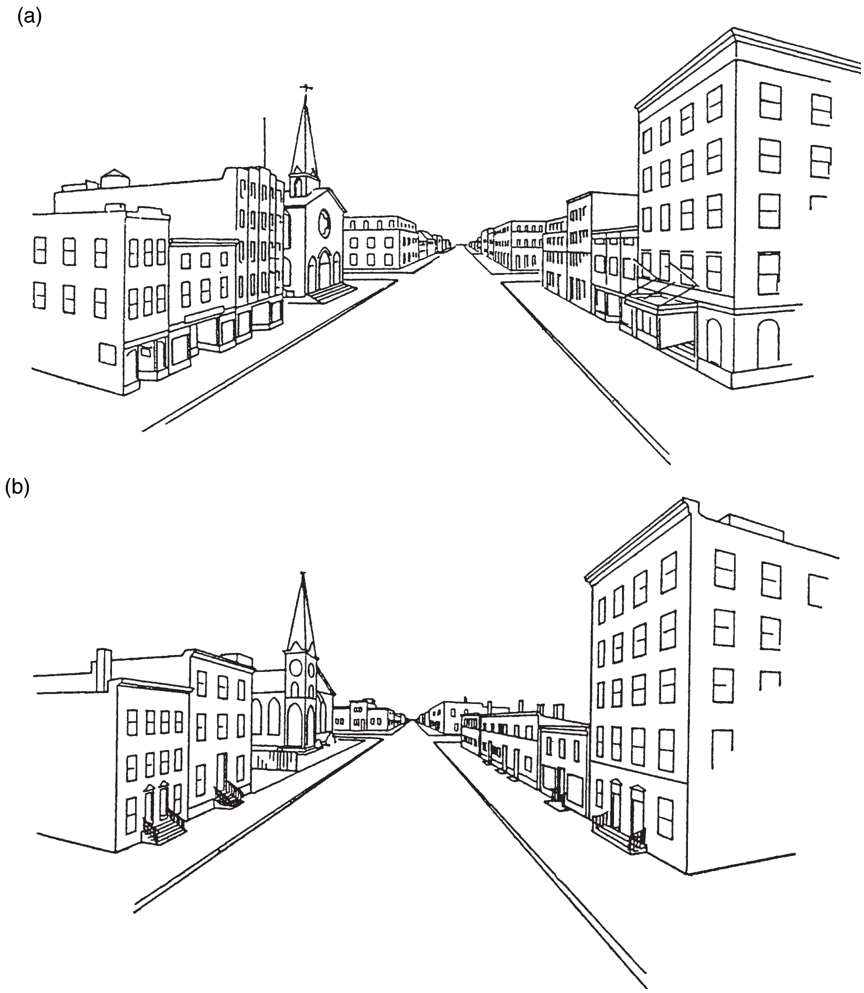


**Figure 3** Illustration of gestalt familiarity explanation of déjà vu (from Dashiell, 1937).

misattribute the sense of familiarity to the entire setting:

> Suppose . . . that after I have visited the picture gallery I go to the next city where there is another gallery. Perhaps in some corner of a room there is some insignificant detail, such as a gilded cornice, that is the same as in the last gallery. This will be seen and recognized, but the feeling of recognition, instead of being confined to the one detail, may be spread over the whole room. (Humphrey, 1923: 140)

The familiar element may not be from objective experience but implanted via imagination or fantasy. MacCurdy (1925) described a déjà vu that he traced to memory fragments from a previous dream. This could also happen with daydreams (Chapman and Mensh, 1951), and Titchener (1928) asserted that our imaginings may leave an even stronger memory trace than real experiences. Sully (1887) also suggested that exquisite prose descriptions may paint a vivid mental picture of a single element – face, object, building façade – and this may have the power to elicit a later déjà vu when a real object resembles it. Multiple familiar elements in combination may have the same effect (Wohlgemuth, 1924; Fleminger, 1991; Findler, 1998; Lampinen, 2002) and may actually increase the probability of déjà vu by summating familiarity while simultaneously interfering with the retrieval of contextual elements necessary for explicit recall (Hintzman, 1988).

Whereas the aforementioned speculation revolves around familiarity associated with unrecognized and embedded stimulus element(s), déjà vu could also result from an affective response (positive or negative) misinterpreted as familiarity (Baldwin, 1889; Allin 1896; Zeidenberg, 1973; Fleminger, 1991; Pagliaro, 1991). Perhaps the strange visceral reaction associated with déjà vu in personal descriptions is not a result, but rather a cause, of the experience (Angell, 1908; Reed, 1974). Seamon et al. (1983) specifically proposed that the type of positive affective response (liking) that is enhanced by mere exposure may underlie déjà vu, and that this may be especially likely with a subliminal exposure which precludes explicit recollection:

> The experience of déjà vu . . . is an expression of the familiarity of a similar stimulus without the retrieval of that earlier event or its context into conscious awareness . . . . Essentially, the same outcome was observed in this study: people liked familiar stimuli without recognizing the basis for their familiarity. In this respect, the finding of target selection by affect in the absence of recognition is similar to the well-known, but poorly understood, phenomenon. (Seamon et al., 1983: 188)

Brown and Marsh (2005) have experimentally evaluated the implicit memory interpretation of déjà vu. They had students superficially process briefly presented scenes of an unfamiliar college campus, and then presented both old and new scenes in a second session (1 or 3 weeks later). In order to model déjà vu, they asked students whether they had actually visited each pictured scene, not just whether it looked familiar. Brown and Marsh (2005) found that the previous presentation of a scene significantly increased mean visit ratings, thus demonstrating that a prior laboratory encounter with a stimulus has the capacity to influence the likelihood of a reaction similar to déjà vu in autobiographical memory.

Hypnosis may also hold promise in modeling déjà vu in the laboratory. Marcuse et al. (1945) reported that a sense of déjà vu accompanies some recollections of stimuli encountered previously under hypnosis. Banister and Zangwill (1941a,b) explored this technique more directly by presenting pictures and odors to hypnotized participants followed by a suggestion to forget. Later, participants were asked to evaluate these same stimuli during full consciousness awareness. Although they were able to elicit a sense of déjà vu in some individuals, they were only moderately successful. O'Connor et al. (2006) have recently applied a similar procedure. Hypnotized participants were told that they would later experience a sense of specific (episodic) familiarity for words with green borders and a sense of unspecified (déjà vu) familiarity for words with red borders. This technique precipitated a déjà-vu-like experience in some participants (5 of 18), although others interpreted the sensation as a tip-of-the-tongue experience (*See* Chapter 2.22). O'Connor et al. noted substantial individual differences in susceptibility to déjà vu, and this should be examined more carefully in future research.

## 2.21.12 Double Perception Explanations

The double perception interpretation of déjà vu rests on the possibility that when an ongoing stream of perception is momentarily dissected or disrupted, this creates the impression of duplicate events:

> . . . you are about to cross a crowded street, and you take a hasty glance in both directions to make sure of a safe passage. Now your eye is caught . . . by the contents of a shop window; and you pause . . . to survey the window before you actually cross the street . . . the preliminary glance up and down, that ordinarily connects with the crossing in a single attentive experience, is disjointed from the crossing; the look at the window, casual as it was, has been able to disrupt the associative tendencies. As you cross, then, you think 'Why, I crossed this street just now'; your nervous system has severed two phases of a single experience, both of which are familiar, and the latter of which appears accordingly as a repetition of the earlier. (Titchener, 1928: 187–188)

Similar speculation is more than a century old (Burnham, 1889; Grasset, 1904) and numerous versions of this explanation have been put forth. One variety proposes that the perceptual experiences both preceding and following the gap are at full awareness, with the ongoing stream of perception being fractured by distraction from either the environment (Conklin, 1935; Leeds, 1944; Tiffin et al., 1946) or our mental activities (Lalande, 1893; Allin, 1896). Allin (1896) suggested that this attentional break between the perception and the reperception moments later is made especially compelling because the reprocessing is faster due to enhanced perceptual fluency (Jacoby and Dallas, 1981).

A second version of the double perception explanation involves a diminished first perception (glance) followed by a second perception at full awareness. The initial perception may be subpar because one's attention is momentarily degraded (1) due to fatigue or distraction (Allin, 1896; Dugas, 1902; West, 1948), (2) because a particular feature is first perceived peripherally and then focally, or (3) from inhibition by other elements in the perceptual array (Dixon, 1971). This diminished-to-full version of the double perception interpretation is lent credibility by several lines of cognitive research. Jacoby and Whitehouse (1989) conducted an investigation inspired by Titchener's (1928) description (see preceding quote). After studying a word list, participants took a recognition test where each word was preceded by a briefly flashed (subliminal) stimulus consisting of the word itself (match), an unrelated word (nonmatch), or a series of symbols (control). Jacoby and Whitehouse (1989) discovered that a new word preceded by itself (match) is more likely to be incorrectly evaluated as old, compared to a new word preceded by a nonmatch or control stimulus. They likened this outcome to déjà vu, and their findings have been replicated by Joordens and Merikle (1992) as well as by Bernstein and Welch (1991), who further suggested that the prime presentation does not have to be subthreshold to elicit this illusion of familiarity.

A second line of research lending credibility to this interpretation is inattentional blindness. Mack and Rock (1998) demonstrated that when searching for a target (+) in a visual display, if a distractor object is inserted along with the target cross after a number of simple trials, most participants will fail to report noticing it, even though the display is well above threshold. Interestingly, this obliviscence is greater when the distracting stimulus appears in the center of the display with the target off to one side. Participants who claim not to have noticed the distracting stimulus show evidence that it was perceived and stored in memory because priming for that distractor stimulus is enhanced on a subsequent indirect test of memory. This processing of unnoticed visual stimuli has also been found in research on cell phone use when driving (Strayer and Johnson, 2001; Strayer et al., 2003).

## 2.21.13 Summary and Future Directions

Déjà vu is a recognition illusion experienced by about two-thirds of individuals, and the incidence generally decreases with age. Most experients have had déjà vu multiple times, generally once every 1 to 6 months in a younger sample (cf. Brown, 2004). Déjà vu experiences are generally brief (several seconds long), triggered by the entire setting, and are more likely to occur indoors, while relaxing, and in the company of friends. The illusion is more likely to occur in individuals with more education, travel experience, and liberal attitudes. Given the rarity of déjà vu, the enigmatic nature of the causative factors, and amorphous response, eliciting a déjà vu experience in the lab may be problematic. However, attempts to model different aspects of the illusion may provide a creative source of research ideas on cognition in general (Seamon et al., 1983; Jacoby and Whitehouse, 1989; Bernstein and Welch, 1991; Joordens and Merikle, 1992; Brown and Marsh, 2005; O'Conner et al., 2006).

There is probably no single cause for déjà vu any more than there is one cause for headaches (Neppe, 1983a). Implicit memory and double perception hold explanatory promise, and evolving research technologies in brain recording and stimulation, psychopharmacology, and virtual reality may also prove useful in clarifying the external (stimuli) and internal (cognitive processing mechanisms) factors that have the capacity to elicit déjà vu (cf. Brown, 2004). Several issues require explication before any complete understanding of the phenomenon can occur, including (1) why déjà vu is less likely with older adults, (2) why déjà vu occurs in both mundane and unique settings, (3) why déjà vu is rarely reported by those with serious memory problems, and (4) why the illusion so often involves a sense of precognition or prior dream.

## References


Abercrombie J (1836) *Inquiries Concerning the Intellectual Powers and the Investigation of Truth*. New York: Harper & Brothers.

Adachi N, Adachi T, Kimura M, Akanuma N, Takekawa Y, and Kato M (2003) Demographic and psychological features of déjà vu experiences in a nonclinical Japanese population. *J. Nerv. Ment. Dis.* 191: 242–247.

Adachi N, Koutroumanidis M, Elwes RDC, et al. (1999) Interictal $^{18}$FDG PET findings in temporal lobe epilepsy with déjà vu. *J. Neuropsychiatry Clin. Neurosci.* 11: 380–386.

Allin A (1896) Recognition. *Am. J. Psychol.* 7: 249–273.

Angell JR (1908) *Psychology*. New York: Henry Holt.

Arlow JA (1959) The structure of the déjà vu experience. *J. Am. Psychoanal. Assoc.* 7: 611–631.

Baldwin JM (1889) *Handbook of Psychology*. New York: Henry Holt.

Bancaud J, Brunet-Bourgin F, Chauvel P, and Halgren E (1994) Anatomical origin of déjà vu and vivid "memories" in human temporal lobe epilepsy. *Brain* 117: 71–90.

Banister H and Zangwill OL (1941a) Experimentally induced olfactory paramnesias. *Br. J. Psychol.* 32: 155–175.

Banister H and Zangwill OL (1941b) Experimentally induced visual paramnesias. *Br. J. Psychol.* 32: 30–51.
Bartlett FC (1932) *Remembering*. Cambridge: Cambridge University Press.
Bernstein IH and Welch KR (1991) Awareness, false recognition, and the Jacoby Whitehouse effect. *J. Exp. Psychol. Gen.* 120: 324–328.
Brauer R, Harrow M, and Tucker GJ (1970) Depersonalization phenomena in psychiatric patients. *Br. J. Psychiatry* 117: 509–515.
Brown AS (1991) A review of the tip of the tongue experience. *Psychol. Bull.* 109: 204–223.
Brown AS (2003) A review of the déjà vu experience. *Psychol. Bull.* 129: 394–413.
Brown AS (2004) *The Déjà Vu Experience*. New York: Psychology Press.
Brown AS, Jones EM, and Davis TL (1995) Age differences in conversational source monitoring. *Psychol. Aging* 10: 111–122.
Brown AS, Porter CL, and Nix LA (1994) A questionnaire evaluation of the déjà vu experience. *Proceedings of Midwestern Psychological Association Convention,* Chicago.
Brown AS and Marsh EJ (2005) Evoking familiarity without recollection: Modeling the déjà vu experience. *Proceedings of Psychonomic Society Convention,* Toronto.
Buck LA (1970) Varieties of consciousness: Comparison of some cognitive characteristics. *Percept. Mot. Skills* 30: 183–186.
Buck LA and Geers MB (1967) Varieties of consciousness: I. Intercorrelations. *J. Clin. Psychol.* 23: 151–152.
Burnham WH (1889) Memory historically and experimentally considered. III. Paramnesia. *Am. J. Psychol.* 2: 431–464.
Calkins MW (1916) *An Introduction to Psychology*. New York: Macmillan.
Carrington H (1931) Déjà-vu'': The sense of the ''already seen.'' *J. Am. Soc. Psychical Res.* 25: 301–306.
Carmichael L (1957) *Basic Psychology: A Study of the Modern Healthy Mind*. New York: Random House.
Chapman AH and Mensh IN (1951) Déjà vu experience and conscious fantasy in adults. *Psychiatr. Q. Suppl.* 25: 163–175.
Claparède E (1951) Recognition and me-ness. In: Rapaport D (ed.) *Organization and Pathology of Thought*, pp. 58–75. New York: Columbia University Press.
Cole M and Zangwill OL (1963) Déjà vu in temporal lobe epilepsy. *J. Neurol. Neurosurg. Psychiatry* 26: 37–38.
Conklin ES (1935) *Principles of Abnormal Psychology*, 2nd edn. New York: Henry Holt.
Crichton-Browne J (1895) The Cavendish Lecture on dreamy mental states. *Lancet* 2: 1–5.
Cutting J and Silzer H (1990) Psychopathology of time in brain disease and schizophrenia. *Behav. Neurol.* 3: 197–215.
Dashiell JF (1937) *Fundamentals of General Psychology*. Boston: Houghton Mifflin.
de Nayer A (1979) Le déjà vu: élaboration d'un modèle d'approche hypothétic. *Psychiatr. Clin.* 12: 92–96.
Dixon NF (1971) *Subliminal Perception: The Nature of a Controversy*. London: McGraw-Hill.
Dugas L (1902) Sur l'interpretation des faits de paramnésie. *Rev. Philos.* 46: 51–58.
Ebbinghaus H (1885) Über das Gedächtnis. In: Dunker HR and Bussenius CE (trans.) *Memory*. New York: Teachers College Press.
Efron R (1963) Temporal perception, aphasia, and déjà vu. *Brain* 86: 403–424.
Ellinwood EH Jr. (1968) Amphetamine psychosis: II. Theoretical implications. *Int. J. Neuropsychiatry* 4: 45–54.
Ellis H (1897) A note on hypnagogic paramnesia. *Mind* 6: 283–287.
Ellis H (1911) *The World of Dreams*. London: Constable and Company.
Findler NV (1998) A model-based theory for déjà vu and related psychological phenomena. *Comput. Hum. Behav.* 14: 287–301.
Fish DR, Gloor P, Quesney LF, and Oliver A (1993) Clinical responses to electrical brain stimulation of the temporal and frontal lobes in patients with epilepsy: Pathophysiological implications. *Brain* 116: 397–414.
Fleminger S (1991) ''The déjà vu experience: Remembrance of things past?'': Comment. *Am. J. Psychiatry* 148: 1418–1419.
Fukuda K (2002) Most experiences of precognitive dream could be regarded as subtype of déjà-vu experiences. *Sleep and Hypnosis* 4: 111–114.
Gallup GH and Newport F (1991) Belief in paranormal phenomena among adult Americans. *The Skeptical Inquirer* 15: 137–146.
Garbutt JC and Gillette GM (1988) Apparent complex partial seizures in a bipolar patient after withdrawal of carbamazepine. *J. Clin. Psychiatry* 49: 410–411.
Gloor P (1991) Neurobiological substrates of ictal behavioral changes. In: Smith DB, Treiman DM, and Trimble MR (eds.) *Neurobehavioral Problems in Epilepsy*, pp. 1–34. New York: Raven Press.
Goodale MA and Milner AD (1992) Separate visual pathways for perception and action. *Trends Neurosci.* 15: 20–25.
Grasset J (1904) La sensation du ''déjà vu.'' *J. Psychol. Norm. Pathol. (Paris)* 1: 17.
Gupta AK, Jeavons PM, Hughes RC, and Covanis A (1983) Aura in temporal lobe epilepsy: Clinical and electroencephalographic correlation. *J. Neurol. Neurosurg. Psychiatry* 46: 1079–1083.
Halgren E, Walter RD, Cherlow DG, and Crandall PH (1978) Mental phenomena evoked by electrical stimulation of the human hippocampal formation and amygdala. *Brain* 101: 83–117.
Harper MA (1969) Déjà vu and depersonalization in normal subjects. *Aus N. Z. J. Psychiatry* 3: 67–74.
Harper M and Roth M (1962) Temporal lobe epilepsy and the phobic anxiety-depersonalization syndrome: I: A comparative study. *Comp. Psychiatry* 3: 129–161.
Hawthorne N (1863) *Our Old Home*. London: Smith, Elder & Co.
Heymans G (1904) Eine enquete und depersonalisation und fausse reconnaissance. *Z. Psychol.* 36: 321–343.
Heymans G (1906) Weitere daten uber depersonalisation und fausse reconnaissance. *Z. Psychol.* 43: 1–17.
Hintzman DL (1988) Judgments of frequency and recognition memory in a multiple-trace memory model. *Psychol. Rev.* 95: 528–551.
Hoffman HG (1997) Role of memory strength in reality monitoring decisions: Evidence from source attribution biases. *J. Exp. Psychol. Learn. Mem. Cogn.* 23: 371–383.
Humphrey G (1923) *The Story of Man's Mind*. Boston: Small, Maynard & Co.
Ide M, Mizukami K, Suzuki T, and Shiraishi H (2000) A case of temporal lobe epilepsy with improvement of clinical symptoms and single photon emission computed tomography findings after treatment with clonazepam. *Psychiatry Clin. Neurosci.* 54: 595–597.
Jackson J (1888) On a particular variety of epilepsy (''intellectual aura''), one case with symptoms of organic brain disease. *Brain* 11: 179–207.
Jacoby LL (1988) Memory observed and memory unobserved. In: Neisser U and Winograd E (eds.) *Remembering Reconsidered: Ecological and Traditional Approaches to the Study of Memory*, pp. 145–177. Cambridge, UK: Cambridge University Press.
Jacoby LL, Allan LG, Collins JC, and Larwill LK (1988) Memory influences subjective experience: Noise judgments. *J. Exp. Psychol. Learn. Mem. Cogn.* 14: 240–247.

Jacoby LL and Dallas M (1981) On the relationship between autobiographical memory and perceptual learning. *J. Exp. Psychol. Gen.* 110: 306–340.

Jacoby LL and Whitehouse K (1989) An illusion of memory: False recognition influenced by unconscious perception. *J. Exp. Psychol. Gen.* 118: 126–135.

Joordens S and Merikle PM (1992) False recognition and perception without awareness. *Mem. Cognit.* 20: 151–159.

Knight EF (1895) *Where Three Empires Meet: A Narrative of Recent Travel in Kashmir, Western Tibet, Gilgit, and Adjoining Countries*. London: Longmans, Green, and Co.

Kohn SR (1983) A ''déjà vu'' review: ''Where or when'': Still mystery and magic in the guise of ''déjà vu.'' *Parapsychol. J. S. Afr.* 4: 70–82.

Kohr RL (1980) A survey of psi experiences among members of a special population. *J. Am. Soc. Psychical Res.* 74: 395–412.

Kolers PA (1973) Remembering operation. *Mem. Cognit.* 1: 347–355.

Kolers PA and Roediger HL (1984) Procedures of mind. *J. Verbal Learn. Verbal Behav.* 23: 425–449.

Lalande A (1893) Des paramnesies. *Rev. Philos.* 36: 485–497.

Lampinen JM (2002) What exactly is déjà vu? *Sci. Am.* 287(3): 103.

Leeds M (1944) One form of paramnesia: The illusion of déjà vu. *J. Am. Soc. Psychical Res.* 38: 24–42.

MacCurdy JT (1925) *The Psychology of Emotion*. New York: Harcourt Brace.

Mack A and Rock I (1998) *Inattentional Blindness*. Cambridge, MA: MIT Press.

Marcuse FL, Hill A, and Keegan M (1945) Identification of posthypnotic signals and responses. *J. Exp. Psychol.* 35: 163–166.

Marková IS and Berrios GE (2000) Paramnesias and delusions of memory. In: Berrios GE and Hodges JR (eds.) *Memory Disorders in Psychiatric Practice*, pp. 313–337. New York: Cambridge University Press.

Maudsley H (1889) The double brain. *Mind* 14: 161–187.

McCready WC and Greeley AM (1976) *The Ultimate Values of the American Population*. Beverly Hills, CA: Sage.

Milner AD and Goodale MA (1995) *The Visual Brain in Action*. Oxford, UK: Oxford University Press.

Morris CD, Bransford JD, and Franks JJ (1977) Levels of processing versus transfer appropriate processing. *J. Verbal Learn. Verbal Behav.* 16: 519–533.

Mullan S and Penfield W (1959) Illusions of comparative interpretation and emotion. *Arch Neurol. Psychiatry* 81: 269–284.

Myers DH and Grant G (1972) A study of depersonalization in students. *Br. J. Psychiatry* 121: 59–65.

Myers FWH (1895) The subliminal self. *Proc. Soc. Psychical Res.* 11: 334–407.

Neppe VM (1983a) The causes of déjà vu. *Parapsychol. J. S. Afr.* 4: 25–35.

Neppe VM (1983b) *The Psychology of Déjà Vu: Have I Been Here Before?* Johannesburg, South Africa: Witwatersrand University Press.

National Opinion Research Center (NORC) (1984) General Social Survey. Retrieved June 2001, from University of California, Berkeley, ''GSS Cumulative Datafile 1972–1998'' at http://sda.berkeley.edu:7502/D3/GSS98/Doc/gs98.htm.

National Opinion Research Center (NORC) (1988) General Social Survey. Retrieved June 2001, from University of California, Berkeley, ''GSS Cumulative Datafile 1972–1998'' at http://sda.berkeley.edu:7502/D3/GSS98/Doc/gs98.htm.

National Opinion Research Center (NORC) (1989) General Social Survey. Retrieved June 2001, from University of California, Berkeley, ''GSS Cumulative Datafile 1972–1998'' at http://sda.berkeley.edu:7502/D3/GSS98/Doc/gs98.htm.

O'Connor AR, Moulin CJA, and Conway MA (2006) Recollective experience and posthypnotic amnesia: The experimental induction of déjà vu. Presented at International Conference on Memory, Sydney, Australia, July 2006.

Osborn HF (1884) Illusions of memory. *North Am. Rev.* 138: 476–486.

Pagliaro L (1991) The déjà vu experience: Remembrance of things past? Reply. *Am. J. Psychiatry* 148: 1418.

Palmer J (1979) A community mail survey of psychic experiences. *J. Am. Soc. Psychical Res.* 73: 221–251.

Palmini A and Gloor P (1992) The localizing value of auras in partial seizures: A prospective and retrospective study. *Neurology* 42: 801–808.

Penfield W and Mathieson G (1974) Memory. Autopsy findings and comments on the role of hippocampus in experiential recall. *Arch. Neurol.* 31: 145–154.

Penfield W and Perot P (1963) The brain's record of auditory and visual experience. *Brain* 86: 596–695.

Pickford RW (1944) Déjà vu in Proust and Tolstoy. *Int. J. Psychoanal.* 25: 155–165.

Quaerens (1870) A prognostic and therapeutic indication in epilepsy. *The Practitioner* 4: 284–285.

Reed G (1974) *The Psychology of Anomalous Experience*, pp. 104–111. Boston: Houghton Mifflin.

Richardson TF and Winokur G (1968) Déjà vu: As related to diagnostic categories in psychiatric and neurosurgical patients. *J. Nerv. Ment. Dis.* 146: 161–164.

Richardson TF and Winokur G (1967) Déjà vu in psychiatric and neurosurgical patients. *Arch. Gen. Psychiatry* 17: 622–625.

Richardson-Klavehn A and Bjork RA (1988) Measures of memory. *Annu. Rev. Psychol.* 39: 475–543.

Roberts RJ, Varney NT, Hulbert KR, et al. (1990) The neuropathology of everyday life: The frequency of partial seizure symptoms among normals. *Neuropsychology* 4: 65–85.

Roediger HL (1996) Memory illusions. *J. Mem. Lang.* 35: 76–100.

Roediger HL and McDermott KB (1993) Implicit memory in normal human subjects. In: Boller F and Grafman J (eds.) *Handbook of Neuropsychology,* vol. 8, pp. 63–131. Amsterdam: Elsevier.

Roth M (1959) The phobic anxiety-depersonalization syndrome. *Proc. R. Soc. Med.* 52: 587–595.

Schacter DL (1987) Implicit memory: History and current status. *J. Exp. Psychol. Learn. Mem. Cogn.* 13: 501–518.

Schacter DL (1996) *Searching for Memory: The Brain, the Mind, and the Past*. New York: Basic Books.

Schacter DL (2001) *The Seven Sins of Memory: How the Mind Forgets and Remembers*. Boston: Houghton Mifflin.

Schneider GE (1969) Two visual systems: Brain mechanisms for localization and discrimination are dissociated by tectal and cortical lesions. *Science* 163: 895–902.

Seamon JG, Brody N, and Kauff DM (1983) Affective discrimination of stimuli that are not recognized: II. Effect of delay between study and test. *Bull. Psychon. Soc.* 21: 187–189.

Sengoku A, Toichi M, and Murai T (1997) Dreamy states and psychoses in temporal lobe epilepsy: Mediating role of affect. *Psychiatry Clin. Neurosci.* 51: 23–26.

Sno HN (2000) Déjà vu and jamais vu. In: Berrios GE and Hodges JR (eds.) *Memory Disorders in Psychiatric Practice*, pp. 338–347. New York: Cambridge University Press.

Sno HN and Draaisma D (1993) An early Dutch study of déjà vu experiences. *Psychol. Med.,* 23: 17–26.

Sno HN and Linszen DH (1990) The déjà vu experience: Remembrance of things past? *Am. J. Psychiatry* 147: 1587–1595.

Sno HN, Linszen DH, and de Jonghe F (1992) Déjà vu experiences and reduplicative paramnesia. *Br. J. Psychiatry* 161: 565–568.

Sno HN, Schalken HFA, de Jonghe F, and Koeter MWJ (1994) The inventory for déjà vu experiences assessment. *J. Nerv. Ment. Dis.* 182: 27–33.

Spatt J (2002) Déjà vu: Possible parahippocampal mechanisms. *J. Neuropsychiatry Clin. Neurosci.* 14: 6–10.

Stern W (1938) *General Psychology: From a Personalistic Standpoint*. New York: Macmillan.

Strayer DL, Drews FA, and Johnston WA (2003) Cell phone-induced failures of visual attention during simulated driving. *J. Exp. Psychol. Appl.* 9: 23–32.

Strayer DL and Johnson WA (2001) Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular telephone. *Psychol. Sci.* 12: 462–466.

Sully J (1887) *Illusions: A Psychological Study*. London: Kegan Paul, Trench.

Taiminen T and Jääskeläinen SK (2001) Intense and recurrent déjà vu experiences related to amantadine and phenylpropanolamine in a healthy male. *J. Clin. Neurosci.* 8: 460–462.

Takaoka K, Ikawa N, and Niwa N (2001) ‘Alice in Wonderland’ syndrome as a precursor of delusional misidentification syndromes. *Int. J. Psychiatry Clin. Pract.* 5: 149–151.

Taylor J (1931) *Selected Writings of J. H. Jackson*, vol. 1. London: Hodder & Stoughton.

Tiffin J, Knight B, and Asher EJ (1946) *The Psychology of Normal People*. Boston: D. C: Heath & Co.

Titchener EB (1928) *A Text-Book of Psychology*. New York: Macmillan.

Turner J (1910) Alcoholic insanity. *J. Mental Sci.* 41.

Weinand ME, Hermann B, Wyler AR, et al. (1994) Long-term subdural strip electrocorticographic monitoring of ictal déjà vu. *Epilepsia* 35: 1054–1059.

Weinstein EA (1969) Patterns of reduplication in organic brain disease. In: Vinken PJ and Bruyn GW (eds.) *Handbook of Clinical Neurology,* vol. 3, pp. 251–257. Amsterdam: North-Holland.

Weinstein EA, Marvin SL, and Keller NJA (1962) Amnesia as a language pattern. *Arch. Gen. Psychiatry* 6: 259–270.

West DJ (1948) The investigation of spontaneous cases. *Proc. Soc. Psychical Res.* 48: 264–300.

Wigan AL (1844) *The Duality of the Mind*. London: Longman, Brown, Green, and Longmans.

Wohlgemuth A (1924) On paramnesia. *Mind* 33: 304–310.

Zeidenberg P (1973) Flashbacks. *Psychiatr. Ann.* 3: 14–19.

# 2.22 Tip of the Tongue Experience

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Routine word retrieval is a remarkable accomplishment when it goes smoothly. We fluidly access and emit tens of thousands of words with hardly a ripple of conscious awareness. On rare occasions, this transition from word knowledge to word output fails and immediately grabs our attention. This tip-of-the-tongue (TOT) experience is common to us all – we are positive that we know the missing word, but are unable to produce it at the moment. William James (1893) provided a colorful and oft-quoted characterization of the TOT experience:

> Suppose we try to recall a forgotten name. The state of our consciousness is peculiar. There is a gap therein; but no mere gap. It is a gap that is intensively active. A sort of wraith of the name is in it, beckoning us in a given direction, making us at moments tingle with the sense of our closeness, and then letting us sink back without the longed-for term. If wrong names are proposed to us, this singularly definite gap acts immediately so as to negate them. They do not fit into its mould. And the gap of one word does not feel like the gap of another, all empty of content as both might seem necessarily to be when described as gaps. . . . The rhythm of a lost word may be there without a sound to clothe it; or the evanescent sense of something which is the initial vowel or consonant may mock us fitfully, without growing more distinct. (James, 1893: 163–164)

One of the primary goals of empirical research on TOTs is to provide a unique picture of an otherwise incredibly rapid and automatic behavior "... similar to how slow-motion photography clarifies the dimensions of a hummingbird's flight" (Brown, 1991: 204). Brown and McNeill (1966) were the first to apply a scientific approach to study this phenomenon. Their research was methodologically and analytically comprehensive and served as a prototype for subsequent investigations on this topic. They presented definitions of relatively rare words ("one who collects stamps" for philatelist; "a secretion of the sperm whale used in the manufacture of perfume" for ambergris) and elicited TOTs on 13% of such trials. Most surprising was how often information about the missing target word (first letter, number of syllables) was available during this experience, suggesting to Brown and McNeill (1966) the concept of generic recall, where the first stage in word retrieval involves accessing abstract (syllables, syllabic stress) and partial (letter) information about the target word. Their investigation set the stage for a steady growth in research on this topic, with the number of articles approximately doubling every decade since their original publication (see summaries by Brown, 1991; Smith, 1994; Schwartz, 2002b). Whereas most investigators use TOTs as a springboard to address mechanisms of memory storage and retrieval, the TOT experience has also been applied to theories of language production (e.g., Caramazza and Miozzo, 1997; Faust et al., 1997; Askari, 1999; Beattie and Coughlan, 1999; Faust et al., 2003; Faust and Sharfstein-Friedman, 2003; Gollan and Acenas, 2004; Golan et al., 2005) and metamemory (Koriat, 1993; Metcalfe et al., 1993; Schwartz, 1998, 1999, 2001a, 2002b; Schwartz and Frazier, 2005; Schwartz and Smith, 1997).

## 2.22.1 Eliciting and Measuring TOTs

TOTs are a universal experience. In both laboratory and diary investigations, it is the rare individual who fails to experience a TOT, and the concept is universally recognized across individuals and cultures. In fact, the "tongue" metaphor characterizes this word generation difficulty across a wide range of languages (45 of 51 sampled by Schwartz, 1999) and is most likely attributable to the subjective impression that the problem is localized in the late stages of oral language production. People report that between one and two TOTs occur per week in everyday life, as reflected in diary studies of naturally occurring TOTs (Cohen and Faulkner, 1986; Reason and Lucas, 1984; Burke et al., 1991; Ecke, 1997; Heine et al., 1999; Schwartz, 2001b; Gollan et al., 2005), as well as in retrospective assessments of TOT incidence (Burke et al., 1991; Sunderland et al., 1986).

Most laboratory studies on TOTs use definitions as target word cues, following Brown and McNeill's (1966) lead. Others have successfully elicited TOTs using faces (Maylor, 1990; Burke et al., 2004; Cross and Burke, 2004), line drawings and pictures (Brown and Nix, 1996; Gollan and Acenas, 2004; Gollan and Brown, 2006), theme songs (Riefer et al., 1995), smells (Jönsson and Olsson, 2003), learned paired associates (Ryan et al., 1982; Metcalfe et al., 1993), and artificially constructed materials (Smith et al., 1991; Schwartz and Smith, 1997; Schwartz, 1998). TOTs elicited in the laboratory are similar to those that occur naturally (Ryan et al., 1982; Burke et al., 1991; Schwartz, 2001b), but the incidence varies considerably depending on the type of cue materials, procedures, and individuals. A summary of 188 outcomes from 72 published articles in **Figure 1** indicates that the incidence of TOTs is generally between 6% and 15% of items (cf. Brown, 1991).

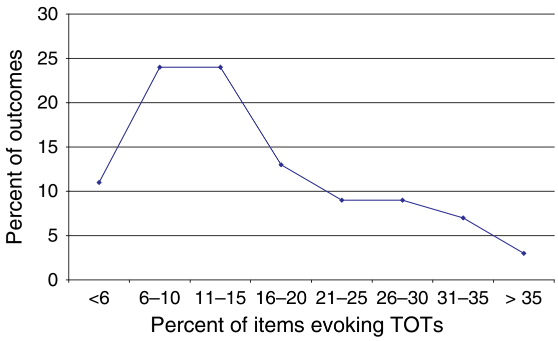


**Figure 1** TOT rate in lab investigations.

Given that TOTs are relatively rare and depend on self-report, there are several measurement issues to consider in this research. First is the distinction between TOT and feeling-of-knowing (FOK) assessments (cf. Yaniv and Meyer, 1987). Typically, an FOK relates to whether one believes that they can later recognize the missing target word, whereas TOTs are triggered by a sense of imminent recall (Maril et al., 2001; Maril et al., 2005). In addition, FOK assessments are requested for all missing target words, whereas TOTs occur spontaneously on only select target words. Researchers also separate positive TOTs (TOT+), where the sought-after target word is the one intended by the experimenter, and negative TOTs (TOT−), where the elusive word differs from the intended target, a distinction made through a recognition test (Brown and McNeill, 1966; Burke et al., 1991). One could argue that a TOT− is a genuine TOT experience, but most exclude these items from analyses (Burke et al., 1991; Rastle and Burke, 1996; Harley and Bown, 1998). There is also the 'fragmentary data problem,' first identified by Brown and McNeill (1966), related to the considerable variation in TOT probability across both participants and stimuli. With each participant's TOTs elicited by a different subset of target words, standard statistical procedures are not well suited to analyzing such data sets.

Finally, there is the phenomenology of TOTs. Informal descriptions of TOTs include such information as James' (1893) observation of a 'tingling' sensation during TOTs and Brown and McNeill's (1966) suggestion that we are 'seized' by, and fall 'under the spell' of, a TOT. Such subjective aspects of experience have received only cursory attention (Schwartz et al., 2000; Schwartz, 2002b), although there seems to be some validity to the sense of imminence, emotionality, and strength associated with TOTs.

## 2.22.2 Influencing TOT Probability

There have been a number of efforts to influence TOT probability through instructions, as well as with primes preceding, and cues following, the target word probe. These manipulations are motivated by efforts to evaluate the mechanisms underlying TOTs. If TOTs are based on a subjective sense of impending or imminent recall of the target word (inferential position), it seems logical that the incidence of TOTs could be manipulated through instructions or motivation. In line with this, Widner et al. (1996) told one group of participants that target words were relatively easy to retrieve, whereas another group was told that they were difficult (the same set of targets were used with both groups). The easy instructions elicited significantly more TOTs, either due to increased motivation to show retrieval competence or greater stress from the struggle to retrieve 'easy' targets (cf. Schwartz, 2002b). In either case, Widner et al. (1996) suggested that an important component of TOTs may be personal expectations about our knowledge base and retrieval competence.

Given that TOTs are sometimes accompanied by related words, it is natural to wonder whether presenting such words influences TOTs in either a positive or negative direction. These experimental manipulations have involved inserting related words either immediately following (cueing) or prior to (priming) the presentation of the target word probe. These efforts have been aimed primarily at differentiating two memory access interpretations of TOTs: blocking and incomplete activation (see discussion later in this chapter).

### 2.22.2.1 Cueing

Jones and Langford (1987) presented cue words that were either (a) phonetically related ('axial' for target 'alchemy'), (b) semantically related ('incubus' for target 'banshee'), (c) both phonetically and semantically related ('abnormality' for target 'anachronism'), or (d) unrelated ('opinionated' for 'cherubic') to the accompanying target word. Phonetically related cue words increased TOTs, whereas semantically related cue words did not, an effect replicated by both Jones (1989) and Maylor (1990a) (cf. Askari, 1999). Unfortunately, cues were not counterbalanced across definitions, and subsequent research suggests that this apparent difference was most likely due to the specific definitions and/or cue words used (Meyer and Bock, 1992; Perfect and Hanley, 1992). Thus, it appears that there is no clear evidence for a related cue word influencing TOT probability. However, this procedure is based on the unlikely assumption that retrieval is not initiated until the definition is completely processed. Rather, it seems more reasonable that retrieval starts well before the entire definition is read. Other investigations have also presented semantic and phonological information related to the target word following the target word probe (Heine et al., 1999; James and Burke, 2000; Abrams et al., 2004), but these generally are designed to influence the resolution rather than the incidence of TOTs, and this research will be covered later in this chapter.

### 2.22.2.2 Priming

A less ambiguous way to influence TOT probability is by presenting related words prior to the target word probe. Although this solves the previously noted problem, it creates another: Participants may become aware of the prime-target relationship and develop strategies to search for target words based on the prime words (cf. Jones, 1989). Rastle and Burke (1996) addressed this problem by embedding target words in an apparently unrelated task preceding the TOT probe session. Participants rated the pronunciation difficulty of a set of words, half of which were targets in the subsequent TOT task. Rastle and Burke (1996) found that there were significantly fewer TOTs on words appearing in the prior prime list, compared to targets that had not been previewed. They further discovered that both shallow (syllable count) and deep (pleasantness) processing of the targets reduced subsequent TOTs.

Several additional investigations have examined the effects of priming with related words, rather than with the target word itself. Burke et al. (2004) presented primes that were either phonologically related (cherry pit) or unrelated (cane) to a celebrity's name (Brad Pitt). Phonologically related primes significantly reduced TOTs relative to unrelated primes, an outcome found with both younger and older adults. Some participants noticed the correspondence between prime and target (see preceding point), and analyses including only unaware subjects yielded a significant prime-related decrease in TOTs for older but not younger participants. Thus, phonological activation can reduce TOTs, but this effect appears to be more pronounced for older adults.

In a similar investigation, Cross and Burke (2004) used semantically (rather than phonologically) related prime words in a proper name retrieval task. Participants were primed with a famous name, either related (Eliza Doolittle) or unrelated (Scarlett O'Hara), to the subsequent target actor (Audrey Hepburn). In the related condition, the actor had actually portrayed the character whose name was primed earlier. There was a slight elevation in TOT rate following a semantically related versus unrelated prime, but this difference was nonsignificant.

Rather than priming the entire target word, James and Burke (2000) exposed participants to various phonological fragments from the target word embedded in a set of 10 prime words preceding the target word cue. With related prime sets, half (5) of the words shared some phonological component ('in*di*gent, *ab*stract, trun*cate*') with the target word ('abdicate'). This type of phonological priming reduced TOTs, relative to unrelated prime sets, where none of the 10 words shared a phonological relation with the target.

#### 2.22.2.3 Target Word Characteristics

Brown and McNeill (1966) originally proclaimed that TOTs occur primarily with rarely used (low-frequency) words, and this assumption has permeated most subsequent research (Naito and Komatsu, 1989; Burke et al., 1991; Askari, 1999; James and Burke, 2000; Lesk and Womble, 2004). Significantly more TOTs have been found with low- versus high-frequency target words (Harley and Bown, 1998; Vitevitch and Sommers, 2003), and target word frequency and TOT probability have been shown to be negatively correlated (Gollan and Silverberg, 2001). Furthermore, Burke et al. (1991) found that about half of naturally occurring TOT target words were so rare that they did not appear in word-frequency norms, and those that did were substantially below the average frequency of occurrence. Smith et al. (1991) experimentally manipulated target word frequency by varying the number of study trials. They found that TOTs were reduced for words with greater frequency, although this difference was significant in only one of two outcomes. In contrast to this, participants rate their naturally occurring TOT targets (diary studies) as relatively familiar (Cohen and Faulkner, 1982; Reason and Lucas, 1984), although data are based on subjective impression rather than objective data.

Another dimension that appears to influence TOT rate is neighborhood density, or the number of words that are phonologically or orthographically similar to the target. More TOTs occur with targets from sparse compared to dense neighborhoods (Harley and Bown, 1998; Vitevitch and Sommers, 2003), suggesting that dense networks may facilitate retrieval. This intriguing finding is based on small and highly selective subsets of words, but this topic certainly warrants additional research. Finally, TOT incidence is considerably higher for proper names compared to other types of target words (common nouns, objects, verbs) in both diary (Burke et al., 1991; Cohen and Faulkner, 1986; Schwartz, 2001b; Gollan et al., 2005) and experimental (Rastle and Burke, 1996; Evrard, 2002) investigations. Interestingly, Gruneberg et al. (1973) found that when individuals are asked to generate their own TOTs ('prospect') they are most likely to search through sets of proper names.

### 2.22.3 Partial Target Word Information

One of the more striking aspects of the TOT experience is that while hanging in linguistic limbo, unable to pull up the elusive target, various aspects of this word often come to mind. In fact, this anecdotal observation was a primary motivation for Brown and McNeill's (1966) original investigation. The meaning of partial target information availability is limited by the fact that it accompanies only some TOTs, and there is considerable variability across studies in how this information is requested, recorded, and reported. Although Brown and McNeill (1966) reported that first letter guesses regarding the target word were correct over half of the time during TOTs, they did not indicate how often such guesses were made. Harley and Bown (1998) found that first letter guess were made on an unimpressive 5% of TOTs, and others don't even provide such information about the missing target word because it is volunteered too infrequently (Schwartz and Smith, 1997; Vitevitch and Sommers, 2003). Thus, one must be careful not to overinterpret the significance of such findings based on low response rates for select items.

For naturally occurring TOTs, approximately two pieces of peripheral information are typically reported, and this rate is lower in lab studies, at less than one piece of information per TOT (Burke et al., 1991; Rastle and Burke, 1996). More than half of naturally occurring TOTs may be accompanied by peripheral information (Cohen and Faulkner, 1986), but this incidence appears to be substantially lower with lab-induced TOTs (Heine et al., 1999). The most salient type of partial target word information is the first letter. Brown and McNeill (1966) originally found that participants correctly guessed the first letter on 57% of attempts, and that 49% of similar sounding (SS) words accompanying TOTs share a common first letter with the intended target. Although subsequent research has yielded a wide range of correct guess accuracy (63%, Yarmey, 1973; 71%, Koriat and Lieblich, 1974; 68%, Rubin, 1975; 40%, Brown and Nix, 1996; 28%, Caramazza and Miozzo, 1997; 54%, Harley and Bown, 1998; 56%, Dahlgren, 1998), the average appears to be around 50% and definitely above chance levels. There is also evidence that individuals can correctly identify the final letter(s) or phoneme during TOTs (Koriat and Lieblich, 1974; Brown and Nix, 1996; Caramazza and Miozzo, 1997), although the accuracy is considerably lower.

The number of syllables in the missing target word also appears to be available on some occasions. Brown and McNeill's (1966) participants were correct 60% of the time guessing number of syllables (from 1 to 5), and later research has yielded somewhat lower rates, averaging around 50% (80%, Koriat and Lieblich, 1974; 35%, Brown and Nix, 1996; 37%, Caramazza and Miozzo, 1997; 54%, Dahlgren, 1998; 55%, Vigliocco et al., 1997; 45%, Gollan and Silverberg, 2001). Although less compelling than first letter guesses, given that the majority of English words are two or three syllables long, these data still suggest that individuals have access to word-form information at greater than chance levels.

Finally, target word gender (masculine, feminine) appears to be accessible during TOTs above chance levels in Italian (71%, Caramazza and Miozzo, 1997; 72%, Miozzo and Caramazza, 1997; 84%, Vigliocco et al., 1997) and French (85%, Ferrand, 2001), although not Hebrew (55%, Gollan and Silverberg, 2001). Thus, most evidence indicates that syntax (gender) as well as orthography (first letter) and general word form (syllables) is accessible during TOTs.

## 2.22.4 Words Related to the Target Word

Individuals often report that nontarget words come to mind when foundering in a TOT experience. These interlopers (Jones, 1989) are immediately identified as incorrect, yet persist in consciousness. They have been variously referred to as relatives (Astell and Harley, 1996), blocking intermediates (Reason and Lucas, 1984), intruders (Schwartz, 1994), candidates (Cohen and Faulkner, 1986), persistent alternatives (Burke et al., 1991; Heine et al., 1999), and ugly stepsisters (Reason and Lucas, 1984). The significance of these interlopers is the subject of a continuing debate that is primarily related to the etiology of TOTs (covered later in this chapter).

Some view interlopers as a byproduct of the TOT experience (cf. Cross and Burke, 2004), reflecting how close one is to the missing target word (Brown and McNeill, 1966). Others see interlopers as causing TOTs: Phonetically or semantically related words are inadvertently retrieved, and their presence hinders successful access to the target word (Jones and Langford, 1987; Jones, 1989; Brown, 1991). Finally, some speculate that these interlopers actually facilitate TOT resolution by sharpening the target word specification (Cohen and Faulkner, 1986).

The majority of naturally occurring (diary) TOTs are accompanied by related words (Reason and Lucas, 1984; Cohen and Faulkner, 1986; Burke et al., 1991; Heine et al., 1999), and their incidence in laboratory-induced TOTs is lower at approximately one-third of TOTs (Burke et al., 1991; Riefer et al., 1995; Brown and Nix, 1996; Harley and Bown, 1998; Riefer, 2002). Most find that semantically related interlopers are more common than phonologically (orthographically) related interlopers (Brown and McNeill, 1966; Riefer et al., 1995; Ecke, 1997; Harley and Bown, 1998), and most are from the same syntactic class as the target word (Burke et al., 1991; Harley and Bown, 1998; Ecke, 2001). It is also common for the interloper and target to share the same initial phoneme and number of syllables (Burke et al., 1991).

## 2.22.5 Resolving TOTs

### 2.22.5.1 Resolution Probability

The vast majority of naturally occurring TOTs are eventually resolved (92%, Burke et al., 1991; 78%, Cohen and Faulkner, 1986; 95%, Heine et al., 1999; 89%, Schwartz, 2001b). About half are resolved within a minute, with most resolved within 1 h (Burke et al., 1991; Schwartz, 2002a). In laboratory research, resolution probability is more difficult to assess because the trial by trial procedure often limits opportunity. Given that most studies allow a maximum of 1 min per trial, any resolutions not occurring within this time frame may not be captured in the procedure. Thus, resolution rates are lower (and highly variable) in laboratory investigations, with an average at around half of TOTs (66%, Gruneberg et al., 1973; 48%, Finley and Sharp, 1989; 38%, Riefer et al., 1995; 22%, Brown and Nix, 1996; 54%, Brédart and Valentine, 1998; 90%, Dahlgren, 1998; 44%, Harley and Bown, 1998; 66%, Beattie and Coughlin, 1999; 50%, Gollan and Silverberg, 2001; 43%, Vitevitch and Sommers, 2003).

### 2.22.5.2 Resolution Process

There are several ways in which the target word can be recovered: mental search, where the individual continues an active memory search; external research, where reference sources or individuals are consulted; and pop-ups, where the word seems to come to mind spontaneously. The incidence of each resolution process varies widely (Read and Bruce, 1982; Reason and Lucas, 1984; Burke et al., 1991; Heine et al., 1999; Schwartz, 2002a) and may partially reflect variations in one's motivation to pursue the inaccessible target word, especially in laboratory TOTs, where one has little personal investment in recovering the elusive word (cf. Brown, 1991). Some controversy surrounds pop-ups because this superficially appears to rely on 'unconscious' mental processes. Whereas some find the incidence quite high, accounting for the majority of resolutions (Finley and Sharp, 1989; Burke et al., 1991; Heine et al., 1999; Schwartz, 2001b), others find the incidence trivial. More specifically, Read and Bruce (1982) found that 3% of TOTs were resolved through 'spontaneous retrieval' and suggested that the incidence in other studies is inflated because pop-ups are striking and hence selectively memorable. Others note that semantic or phonetic cues that one encounters in the environment may trigger the missing target word without conscious awareness of the connection between cue and missing target (Abrams et al., 2003).

Related to pop-ups is the possibility of persistent subthreshold activation of the target word immediately following the TOT. Yaniv and Meyer (1987) suggested that "...the memory trace of a currently inaccessible item may be at least partially primed for a period of time after information is processed from an initial probe question..." (p. 188). In support of such speculation, Yaniv and Meyer (1987) found that immediately after an unresolved TOT, lexical decision latencies were faster for TOT targets than for unrelated words, suggesting a heightened activation level. However, Connor et al. (1992) replicated Yaniv and Meyer (1987) with a 1-week separation between the TOT and lexical decision task, an interval that logically exceeds any continuing activation. Connor et al. (1992) suggested that rather than continuing subthreshold activation, words from well-known categories of information are more likely to lead to both higher TOT incidence and faster lexical decisions (cf. Naito and Komatsu, 1989).

### 2.22.5.3 Resolution through Cueing

Different procedures have been used to aid TOT resolution. Re-presenting the same target-word cue after a delay has been moderately successful (15%, Brown and Nix, 1996; 12%, Schwartz, 1998), as well as providing the first letter of the missing target word (Freedman and Landauer, 1966; Brennen et al., 1990; Heine et al., 1999). Others have used a more subtle manipulation: burying phonetic fragments of the target word in a set of words processed immediately following the TOT. This procedure is similar to one used to manipulate TOT probability (see earlier discussion). James and Burke (2000) found that processing five words sharing phonological components with the target word (embedded in a 10-word set) while in a TOT improved resolution probability, compared to an unrelated set of words. In a more focused effort to specify which phonological element(s) are important, White and Abrams (2002) found that only the first, but not the middle or last, syllable can enhance TOT resolution. Refining this even further, Abrams et al. (2004) discovered that the first letter alone is insufficient, but that the entire first syllable is needed. Finally, Abrams and Rodriguez (2005) found that the first phoneme facilitated TOT resolution only if the target ('rosary') is cued with a word from a different syntactic category ('robust') from the target. When cue word shares the same syntactic class ('robot') with the target, a common initial phoneme is of no assistance in TOT resolution. Thus, phonological activation has the capacity to add activation to the unavailable TOT target word, facilitating resolution of the TOT, but this occurs only if the cue word differs in syntax from the target.

## 2.22.6 Etiology of TOTs

### 2.22.6.1 Direct Access Explanations

Perhaps the liveliest issue in TOT research in the past decade involves identifying the cause of the experience. As noted earlier, Brown and McNeill (1966) originally proposed that TOTs reflect generic recall, where access to specific words involves first sorting through word sets with similar meaning or phonology and then narrowing this down to the particular target. Their ideas did not capture the imagination of researchers in the field, but other interpretations emerged based on the presumption that the TOT reflects a partial activation of the target word. These direct access interpretations fall into two different categories: blocking and incomplete activation. The blocking explanations assume that access to the missing target word is hindered by the presence of other words related to the target (interlopers) (Woodworth, 1938). This perspective motivated some to use related words in an attempt to precipitate TOTs (Reason and Lucas, 1984; Jones and Langford, 1987; Jones, 1989). However, this theory has not received clear empirical support (Meyer and Bock, 1992; Perfect and Hanley, 1992) and cannot easily account for the absence of interlopers for many TOT experiences.

A more likely cause of TOTs is incomplete activation, posited by Burke et al. (1991) and derived from research on language production. Under this interpretation, word production occurs in sequential stages, where activation is passed from a semantic to a phonological representation of the word (Node Structure Theory, or NST). On most occasions, sufficient activation is transmitted from the semantic to the phonological nodes, but on rare occasions the activation conveyed to the phonological nodes is inadequate for complete word production (Burke et al., 1991). Burke et al.'s (1991) version of NST is the transmission deficit hypothesis (TDH). This is the most prominent of incomplete activation theories applied to TOT research, and Burke et al. (1991) speculated that the three most important factors affecting the transmission of activation are (a) recency of word experience, (b) frequency of word experience, and (c) age of the individual. More specifically, a TOT is less likely if the target word has been recently experienced, the word is frequently experienced, and the individual is younger.

Several lines of evidence support TDH. First, individuals can access some aspects of the missing target word (e.g., first letter) because the activation passed along to the lexical nodes is sufficient to make accessible some aspects of the word form without activating the entire lexical entry. The occurrence of interlopers can also be accounted for by TDH. Phonological nodes are shared across multiple words (e.g., 'cha' is shared by 'charity' and 'chastity'), and the activation of a shared node can transmit priming backwards to the semantic level and supply sufficient activation to another word structurally related to the target. TDH is also supported by an age-related decrease in partial target word information (Burke et al., 1991; Rastle and Burke, 1996) and interlopers (Burke et al., 1991). The age-related decline in transmission of activation reduces phonological activation, making elements of the target word (first letter, etc.) less available and reducing the amount of backward activation to related words.

Experimental efforts to increase phonological activation of target word components appear to influence TOTs in a manner congruent with TDH. As described earlier in this chapter, James and Burke (2000) found that phonological components of the target not only reduce TOTs when presented as primes preceding the definition, but also increase TOT resolution when presented as cues following the definition. Rastle and Burke (1996) further found that presenting target words in a prior prime list decreases the number of TOTs, suggesting that recent encounter facilitates the transmission of activation, congruent with TDH (Heine et al., 1999; White and Abrams, 2002; Abrams et al., 2001, 2004).

### 2.22.6.2 Inferential Explanations

In contrast to direct access, an alternative interpretation is that TOTs reflect an individual's inference about their personal knowledge (cf. Schwartz and Smith, 1997), rather than conveying information concerning the partial activation of the target word. The most thoroughly detailed inferential interpretation is the metacognitive control theory of Schwartz (1999, 2001a, 2002b), which suggests that TOTs arise from an individual's inference about retrieval probability for that particular word. When retrieval fails, we evaluate how accessible a target word should be. If higher than a certain threshold, we experience a TOT. If lower, we have a 'don't know' (DK) response. This evaluation of word accessibility serves to maintain our retrieval effort longer, compared to words not so assessed, yielding higher recall rates following TOT versus DK states and more time spent in the retrieval effort (Schwartz, 2001a). Koriat (1993) also suggested that a TOT does not reflect special access to the unavailable target word, but is based on partial information retrieved when searching for the word, whether or not these fragmentary data are related to the missing target. Thus, our sense of imminent recall derives not from how close we are to the target word, but how much partial information comes to mind.

Inferential theorists point to the fact that TOTs can occur for artificially constructed stimuli (TOTimals, or made-up animals) that have not been given a name (Schwartz, 1998), and that the likelihood of a TOT is directly related to the amount of target word information provided in the retrieval cue (Schwartz and Smith, 1997). Schwartz (1998) also argued that inferential theories receive support from the fact that we can experience TOTs for nonexistent target words. 'Illusory' TOTs for a fictitious fact ("What is the name of the legendary floating island in ancient Greece?"; "What is the capital of Bormea?") cannot be based on partial target word information because none exists. However, one difficulty with such a conclusion is that these stimulus materials were ineffective in eliciting TOTs with older adults because they universally recognized that the questions had no answer (Schwartz, 2002b). Others argue that illusory TOTs may actually be negative TOTs (TOT−) for real target words, with participants making perceptual or interpretative errors in reading the 'definitions' (Taylor and MacKay, 2002).

In summary, it is possible that both direct access and inferential components contribute to the TOT experience (Schwartz, 1994). Direct access is supported by our ability to correctly access parts of the missing word. And because every TOT relies, to some extent, on our personal cognitive evaluations of our knowledge store and retrieval capability, inferential theories have some place in the explanatory picture.

## 2.22.7 Individual Differences

### 2.22.7.1 Age

A ubiquitous finding in TOT research is that older adults experience more TOTs than younger adults. This difference has been found in both diary studies (Cohen and Faulkner, 1986; Burke et al., 1991; Heine et al., 1999) and laboratory investigations (Burke et al., 1991; Brown and Nix, 1996; Rastle and Burke, 1996; Dahlgren, 1998; Heine et al., 1999; James and Burke, 2000; Gollan and Silverberg, 2001; White and Abrams, 2002; Vitevitch and Sommers, 2003; Cross and Burke, 2004; Gollan and Brown, 2006). What is less clear is to what extent this reflects a verbal deficit (decrement theory) or a verbal surplus (incremental-knowledge theory) (Schwartz and Frazier, 2005), keeping in mind that these two positions are not necessarily mutually exclusive (Schwartz and Frazier, 2005; Gollan and Brown, 2006). Burke et al. (1991) suggested that aging naturally diminishes the amount of semantic to phonological priming that occurs during normal word production, and that an increase in TOTs reflects this growing deficit. Gollan and Brown (2006) argued that older adults also have more opportunities to experience TOTs because they have larger vocabularies than younger adults. When compared using a set of words that both groups know equally well, older and younger adults experienced similar numbers of TOTs. Gollan and Brown (2006) further suggested that the negative effects of aging (NST) are more pronounced on easier words because they are closer to ceiling levels of activation. Regardless of the position, any group comparison using laboratory investigations with a common set of target words is problematic. If TOTs are viewed as deficiency and analyzed relative to all unsuccessful items (cf. Brown, 1991), the more verbal group may show a greater deficit because they have fewer nonrecalled items in their baseline. If TOTs are viewed as a surplus and analyzed relative to correct retrievals, the group differences often disappear (cf. Gollan and Brown, 2006). Given that most lab studies use a fixed set of targets, one may or may not find group differences, depending on one's orientation (cf. Gollan and Brown, 2006). It is likely that both verbal deficit and surplus mechanisms contribute to age-related TOT differences, although it should be noted that proper names always show substantial age differences, even when knowledge levels are equated (Cross and Burke, 2004).

At the other end of the age spectrum, TOTs have also been documented among children, but this area remains relatively unexplored. Apart from informal documentation (Wellman, 1977; Elbers, 1985), there are only three published reports using standard laboratory designs. All involve a comparison of normal and language-disabled (LD) children (Faust et al., 1997; Faust et al., 2003; Faust and Sharfstein-Friedman, 2003) and suggest that the incidence of TOTs in normal children is in the same range as that found in adults (11% in grades 2 to 3; Faust et al., 1997; 19% in grades 3 to 4, Faust et al., 2003; 7% in grades 7 to 8, Faust and Sharfstein-Friedman, 2003). Also similar to adults, partial phonemic and semantic information is often available during TOTs. This research also shows that TOT rates for LD children are twice that of normal children, and that partial information available during their TOTs suggest that LD children suffer deficiencies in phonetic but not semantic access to the target words.

### 2.22.7.2 Language Competence

The relationship between vocabulary ability and TOTs is ambiguous. Whereas Dahlgren (1998) found that those with high verbal ability have significantly more TOTs than those with low verbal ability, Heine et al. (1999) found a nonsignificant correlation between laboratory-induced TOT rate and vocabulary level. Burke et al. (1991) discovered no correlation between TOTs and vocabulary for naturally occurring TOTs. For lab-induced TOTs, Burke et al. (1991) found no correlation for younger adults but a significant negative correlation for older adults. The inconsistency in these outcomes may be due to the restricted range of vocabulary ability in the particular participant samples, or the selective nature of stimulus materials. An evaluation of the relationship of verbal ability to TOTs should be a routine fixture in future research because the interaction of verbal ability level and word frequency may be an important factor affecting TOT rate (cf. Gollan and Brown, 2006).

Another verbal ability difference examined in TOT research involves monolinguals versus bilinguals. This research has consistently shown that bilinguals experience more TOTs than monolinguals (Gollan and Silverberg, 2001; Gollan and Acenas, 2005; Gollan et al., 2005; Gollan and Brown, 2006), a difference most likely due to bilinguals' reduced use of words (on the average) in both languages (Gollan and Silverberg, 2001; Gollan and Acenas, 2005). This outcome is congruent with TDH (Burke et al., 1991) in that the level of phonetic activation for bilinguals' vocabulary words is less than that for monolinguals because the average usage per word is lower.

## 2.22.8 Summary

TOTs are a nearly universal experience across a broad range of cultures. TOTs are elicited in the laboratory for around 10–15% of targets, and such lab-induced TOTs have a reasonable similarity to those occurring naturally in diary studies. Proper names are especially likely to trigger TOTs. The missing target comes to mind on most occasions, although this rate is lower in laboratory than in diary investigations. During a TOT, related words (interlopers) come to mind frequently, and certain features of the missing target word (e.g., first letter, number of syllables) appear accessible even when the target word is not. Phonological information about the missing target word appears to reduce TOT incidence and increase TOT resolution. TOTs are more prevalent among older (versus younger) adults and among bilinguals (versus monolinguals). Although some have suggested that TOTs result from target word blocking caused by interlopers or inferences about target word accessibility, most research supports the idea that TOTs result from insufficient phonological activation of the target word.

## References


Abrams L and Rodriguez EL (2005) Syntactic class influences phonological priming of tip of-the-tongue resolution. *Psychon. Bull. Rev.* 12: 1018–1023.

Abrams L, White KK, and Eitel SL (2003) Isolating phonological components that increase tip-of-the-tongue resolution. *Mem. Cogn.* 31: 1153–1162.

Askari N (1999) Priming effects on tip-of-the-tongue states in Farsi-English bilinguals. *J. Psycholinguist. Res.* 28: 197–212.

Astell AJ and Harley TA (1996) Tip-of-the-tongue states and lexical access in dementia. *Brain Lang.* 54: 196–215.

Beattie G and Coughlan J (1999) An experimental investigation of the role of iconic gestures in lexical access using the tip-of-the tongue phenomenon. *Br. J. Psychol.* 90: 35–56.

Brédart S and Valentine T (1998) Descriptiveness and proper name retrieval. *Memory* 6: 199–206.

Brennen T, Baguley T, Bright J, and Bruce V (1990) Resolving semantically induced tip-of the-tongue states for proper nouns. *Mem. Cogn.* 18: 339–347.

Brown AS (1991) A review of the tip of the tongue phenomenon. *Psychol. Bull.* 109: 204–223.

Brown AS and Nix LA (1996) Age-related changes in the tip-of-the-tongue experience. *Am. J. Psychol.* 109: 79–91.

Brown R and McNeill D (1966) The ''tip of the tongue'' phenomenon. *J. Verb. Learn. Verb. Behav.* 5: 325–337.

Burke DM, Locantore JK, and Austin AA (2004) Cherry pit primes Brad Pitt: Homophone priming effects on young and older adults' production of proper names. *Psychol. Sci.* 15: 164–170.

Burke DM, MacKay DG, Worthley JS, and Wade E (1991) On the tip of the tongue: What causes word finding failures in young and older adults? *J. Mem. Lang.* 30: 542–579.

Caramazza A and Miozzo M (1997) The relation between syntactic and phonological knowledge in lexical access: Evidence from the ''tip-of-the-tongue'' phenomenon. *Cognition* 64: 309–343.

Cohen G and Faulkner D (1986) Memory for proper names: Age differences in retrieval. *Br. J. Develop. Psychol.* 4: 187–197.

Connor LT, Balota DA, and Neely JH (1992) On the relation between feeling of knowing and lexical decision: Persistent subthreshold activation or topic familiarity? *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 544–554.
Cross ES and Burke DM (2004) Do alternative names block young and older adults' retrieval of proper names? *Brain Lang.* 89: 174–181.
Dahlgren DJ (1998) Impact of knowledge and age on tip-of-the-tongue rates. *Exp. Aging Res.* 24: 139–153.
Ecke P (1997) Tip of the tongue states in first and foreign languages: Similarities and differences of lexical retrieval failures. In: Díaz L and Pérez C (eds.) *Proceedings of the EUROSLA 7 Conference*, pp. 505–514. Barcelona, Spain: Universitat Pompeu Fabra.
Ecke P (2001) Lexical retrieval in a third language: Evidence from errors and tip-of-the-tongue states. In: Cenoz J, Hufeisen B, and Jessner U (eds.) *Cross-Linguistic Aspects of L3 Acquisition*, pp. 90–114. Clevedon: Multilingual Matters.
Elbers L (1985) A tip-of-the-tongue experience at age two? *J. Child Lang.* 12: 353–365.
Evrard M (2002) Ageing and lexical access to common and proper names in picture naming. *Brain Lang.* 81: 174–179.
Faust M, Dimitrovsky L, and Davidi S (1997) Naming difficulties in language-disabled children: Preliminary findings with the application of the tip-of-the-tongue paradigm. *J. Speech Lang. Hear. Res.* 40: 1026–1036.
Faust M, Dimitrovsky L, and Shacht T (2003) Naming difficulties in children with dyslexia: Application of the tip-of-the-tongue paradigm. *J. Learn. Disabil.* 36: 203–215.
Faust M and Sharfstein-Friedman S (2003) Naming difficulties in adolescents with dyslexia: Application of the tip-of-the-tongue paradigm. *Brain Cogn.* 53: 211–217.
Ferrand L (2001) Grammatical gender is also on the tip of French tongues. *Curr. Psychol. Lett. Behav. Brain Cogn.* 5: 7–20.
Finley GE and Sharp T (1989) Name retrieval by the elderly in the tip-of-the-tongue paradigm: Demonstrable success in overcoming initial failure. *Educ. Gerontol.* 15: 259–265.
Freedman JL and Landauer TK (1966) Retrieval of long-term memory: ''Tip-of-the-tongue'' phenomenon. *Psychon. Sci.* 4: 309–310.
Gollan TH and Acenas LA (2004) What Is a TOT? Cognate and translation effects on tip of-the-tongue states in Spanish-English and Tagalog-English bilinguals. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 246–269.
Gollan TH and Brown AS (2006) From tip-of-the-tongue (TOT) data to theoretical implications: When more TOTs means better retrieval. *J. Exp. Psychol. Gen.* 135: 462–483.
Gollan TH and Silverberg NB (2001) Tip-of-the-tongue states in Hebrew-English bilinguals. *Bilingualism Lang. Cogn.* 4: 63–83.
Gollan TH, Bonanni MP, and Montoya RI (2005) Proper names get stuck on bilingual and monolingual speakers' tip-of-the-tongue equally often. *Neuropsychology* 19: 278–287.
Gruneberg MM, Smith RL, and Winfrow P (1973) An investigation into response blockaging. *Acta Psychol.* 37: 187–196.
Harley TA and Bown HE (1998) What causes a tip-of-the-tongue state? Evidence for lexical neighbourhood effects in speech production. *Br. J. Psychol.* 89: 151–174.
Heine MK, Ober BA, and Shenaut GK (1999) Naturally occurring and experimentally induced tip-of-the-tongue experiences in three adult age groups. *Psychol. Aging* 14: 445–457.
James L and Burke DM (2000) Phonological priming effects on word retrieval and tip-of the-tongue experiences in young and older adults. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1378–1391.
James W (1893) *The Principles of Psychology: Vol. 1*. New York: Holt.
Jones GV (1989) Back to Woodworth: Role of interlopers in the tip-of-the-tongue phenomenon. *Mem. Cogn.* 17: 69–76.
Jones GV and Langford S (1987) Phonological blocking in the tip of the tongue state. *Cognition* 26: 115–122.
Jönsson FU and Olsson MJ (2003) Olfactory metacognition. *Chem. Senses* 28: 651–658.
Koriat A (1993) How do we know that we know? The accessibility account of the feeling of knowing. *Psychol. Rev.* 100: 609–639.
Koriat A and Lieblich I (1974) What does a person in a ''TOT'' state know that a person in a ''don't know'' state doesn't know. *Mem. Cogn.* 2: 647–655.
Lesk VE and Womble SP (2004) Caffeine, priming, and tip of the tongue: Evidence for plasticity in the phonological system. *Behav. Neurosci.* 118: 453–461.
Maril A, Simons JS, Weaver JJ, and Schacter DL (2005) Graded recall success: An event-related fMRI comparison of tip of the tongue and feeling of knowing. *Neuroimage* 24: 1130–1138.
Maril A, Wagner AD, and Schacter DL (2001) On the tip of the tongue: An event-related fMRI study of semantic retrieval failure and cognitive conflict. *Neuron* 31(4): 653–660.
Maylor EA (1990) Age, blocking and the tip of the tongue state. *Br. J. Psychol.* 81: 123–134.
Metcalfe J, Schwartz BL, and Joaquim SG (1993) The cue-familiarity heuristic in metacognition. *J. Exp. Psychol. Learn. Mem. Cogn.* 19: 851–864.
Meyer AS and Bock K (1992) The tip-of-the-tongue phenomenon: Blocking or partial activation? *Mem. Cogn.* 20: 715–726.
Miozzo M and Caramazza A (1997) Retrieval of lexical-syntactic features in tip-of-the tongue states. *J. Exp. Psychol. Learn. Mem. Cogn.* 23: 1410–1423.
Naito M and Komatsu S (1989) Effects of conceptually driven processing on perceptual identification. *Jpn. J. Psychol.* 31: 45–56.
Perfect TJ and Hanley JR (1992) The tip-of-the-tongue phenomenon: Do experimenter presented interlopers have any effect? *Cognition* 45: 55–75.
Rastle KG and Burke DM (1996) Priming the tip of the tongue: Effects of prior processing on word retrieval in young and older adults. *J. Mem. Lang.* 35: 585–605.
Read JD and Bruce D (1982) Longitudinal tracking of difficult memory retrievals. *Cogn. Psychol.* 14: 280–300.
Reason JT and Lucas D (1984) Using cognitive diaries to investigate naturally occurring memory blocks. In: Harris J and Morris PE (eds.) *Everyday Memory, Actions, and Absent-mindedness*, pp. 53–70. London: Academic.
Riefer DM (2002) Comparing auditory vs. visual stimuli in the tip-of-the-tongue phenomenon. *Psychol. Rep.* 90: 568–576.
Riefer DM, Keveri MK, and Kramer DLF (1995) Name that tune: Eliciting the tip-of-the tongue experience using auditory stimuli. *Psychol. Rep.* 77: 1379–1390.
Rubin DC (1975) Within word structure in the tip-of-the-tongue phenomenon. *J. Verb. Learn. Verb. Behav.* 14: 392–397.
Ryan MR, Petty CR, and Wenzlaff RM (1982) Motivated remembering efforts during tip-of-the-tongue states. *Acta Psychol.* 51: 137–147.
Schwartz BL (1994) Sources of information in metamemory: Judgments of learning and feelings of knowing. *Psychon. Bull. Rev.* 1: 357–375.
Schwartz BL (1998) Illusory tip-of-the-tongue states. *Memory* 6: 623–642.
Schwartz BL (1999) Sparkling at the end of the tongue: The etiology of tip-of-the-tongue phenomenology. *Psychon. Bull. Rev.* 6: 379–393.
Schwartz BL (2001a) The relation of tip-of-the-tongue states and retrieval time. *Mem. Cogn.* 29: 117–126.
Schwartz BL (2001b) The phenomenology of naturally-occurring tip-of-the-tongue states: A diary study. In: Shohov SP (ed.) *Advances in Psychology Research,* Vol. 8, pp. 73–84. Huntington, NY: Nova Science Publishers.
Schwartz BL (2002a) The strategic control of retrieval during tip-of-the-tongue states. *Korean J. Think. Prob. Slvg.* 12: 27–37.

Schwartz BL (2002b) *Tip-of-the-Tongue States: Phenomenology, Mechanism, and Lexical Retrieval*. Mahwah, NJ: Erlbaum.
Schwartz BL and Frazier LD (2005) Tip-of-the-tongue states and aging: Contrasting psycholinguistic and metacognitive perspectives. *J. Gen. Psychol.* 132: 377–391.
Schwartz BL and Smith SM (1997) The retrieval of related information influences tip-of the-tongue states. *J. Mem. Lang.* 36: 68–86.
Schwartz BL, Travis DM, Castro AM, and Smith SM (2000) The phenomenology of real and illusory tip-of-the-tongue states. *Mem. Cogn.* 28: 18–27.
Smith SM (1994) Frustrated feelings of imminent recall: On the tip of the tongue. In: Metcalfe J and Shimamura AP (eds.) *Metacognition: Knowing about Knowing*, pp. 27–45. Cambridge, MA: The MIT Press.
Smith SM, Brown JM, and Balfour SP (1991) TOTimals: A controlled experimental method for studying tip-of-the-tongue states. *Bull. Psychon. Soc.* 29: 445–447.
Sunderland A, Watts K, Baddeley AD, and Harris JE (1986) Subjective memory assessment and test performance in elderly adults. *J. Gerontol.* 41: 376–384.
Taylor JK and MacKay DG (2002) Tip-of-the-tongue phenomena: Gold mine or can of worms? Review of B. L. Schwartz, *Tip-of-the-Tongue States: Phenomenology, Mechanisms, and Lexical Retrieval*. *Am. J. Psychol.* 116: 291–297.
Vigliocco G, Antonini T, and Garrett MF (1997) Grammatical gender is on the tip of Italian tongues. *Psychol. Sci.* 8: 314–317.
Vitevitch MS and Sommers MS (2003) The facilitative influence of phonological similarity and neighborhood frequency in speech production in younger and older adults. *Mem. Cogn.* 31: 491–504.
Wellman HM (1977) Tip of the tongue and feeling of knowing experiences: A developmental study of memory monitoring. *Child Develop.* 48: 13–21.
White KK and Abrams L (2002) Does priming specific syllables during tip-of-the-tongue states facilitate word retrieval in older adults? *Psychol. Aging* 17: 226–235.
Widner RL, Smith SM, and Graziano WG (1996) The effects of demand characteristics on the reporting of tip-of-the-tongue and feeling-of-knowing states. *Am. J. Psychol.* 109: 525–538.
Woodworth RS (1938) *Experimental Psychology*. New York: Henry Holt.
Yaniv I and Meyer DE (1987) Activation and metacognition of inaccessible stored information: Potential bases for incubation effects in problem-solving. *J. Exp. Psychol. Learn. Mem. Cogn.* 13: 187–205.
Yarmey AD (1973) I recognize your face, but I can't remember your name: Further evidence on the tip-of-the-tongue phenomenon. *Mem. Cogn.* 1: 287–290.

# 2.23 Theories of Recognition Memory

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## 2.23.1 Introduction

Current theories of recognition memory include quantitative models and detailed neural/computational models. In this chapter we review three general classes of quantitative memory models (i.e., threshold, signal detection, and hybrid models) and assess each model's ability to account for results from a variety of recognition paradigms. Implications of these findings for neural/computational models (e.g., network models of the medial temporal lobes) are then considered.

For each of the models, we first describe the core assumptions, point out the motivations underlying these assumptions, and describe their major predictions. We then evaluate each class of model in light of the empirical literature. In general, the results indicate that pure threshold and pure signal detection models are not consistent with the existing data, whereas several hybrid models (those that include both signal detection and threshold processes) are consistent with a majority of the results.

One of the most direct ways of testing quantitative recognition models is to use a receiver operating characteristic (ROC) analysis, and this method has been applied most extensively in studies of item recognition. Recently, ROC methods have also been applied to other types of recognition, such as relational (e.g., source and associative), remember/know, and exclusion recognition tests. Taken together, these various recognition tasks provide a rich set of data with which to evaluate these models. Neural data, including recent studies of amnesia, event-related potentials (ERPs), and functional magnetic resonance imaging (fMRI), also prove useful in assessing these models. We begin by describing exactly what ROCs are and why they are particularly useful in evaluating models of recognition memory.

### 2.23.1.1 What Is an ROC?

An ROC is a function that relates the proportion of correctly recognized target items (i.e., the hit rate) to the proportion of incorrectly recognized lure items (i.e., the false alarm rate) across variations in response bias (i.e., the propensity to make a positive recognition response). In a test of item recognition memory the hit rate is the probability of correctly accepting an old (studied) item as old, and the false alarm rate is the probability of incorrectly accepting a new (unstudied) item as old. ROCs are based on signal detection theory, which assumes that recognition memory (standard item recognition in this case) can be described as a set of two overlapping distributions, one for old or studied items and one for new or unstudied items. The distributions reflect the variation in 'memory strength' (a term that has been interpreted in many different ways, but is commonly thought to be similar to familiarity) for these two sets of stimuli (see **Figure 1(a)** for an illustration). In order to make a binary old/new recognition decision, an individual is assumed to select some level of memory strength as a criterion; items with strengths greater than the criterion are then accepted as old, and items with strengths less than the criterion are rejected as new. However, ROCs contain multiple points collected under different levels of response bias, rather than just the one point generated in old/new paradigms.

The multiple points in ROCs can be obtained in various ways, but by far the most common is the confidence rating method (for comprehensive discussions of general ROC methods see Wickens, 2002; Macmillan and Creelman, 2005). For example, after studying a list of items, subjects are presented with a mixture of old and new items and are required to indicate how confidently they recognize each item on a confidence scale, such as the commonly used six-point scale, with 1 labeled 'Sure New' and 6 labeled

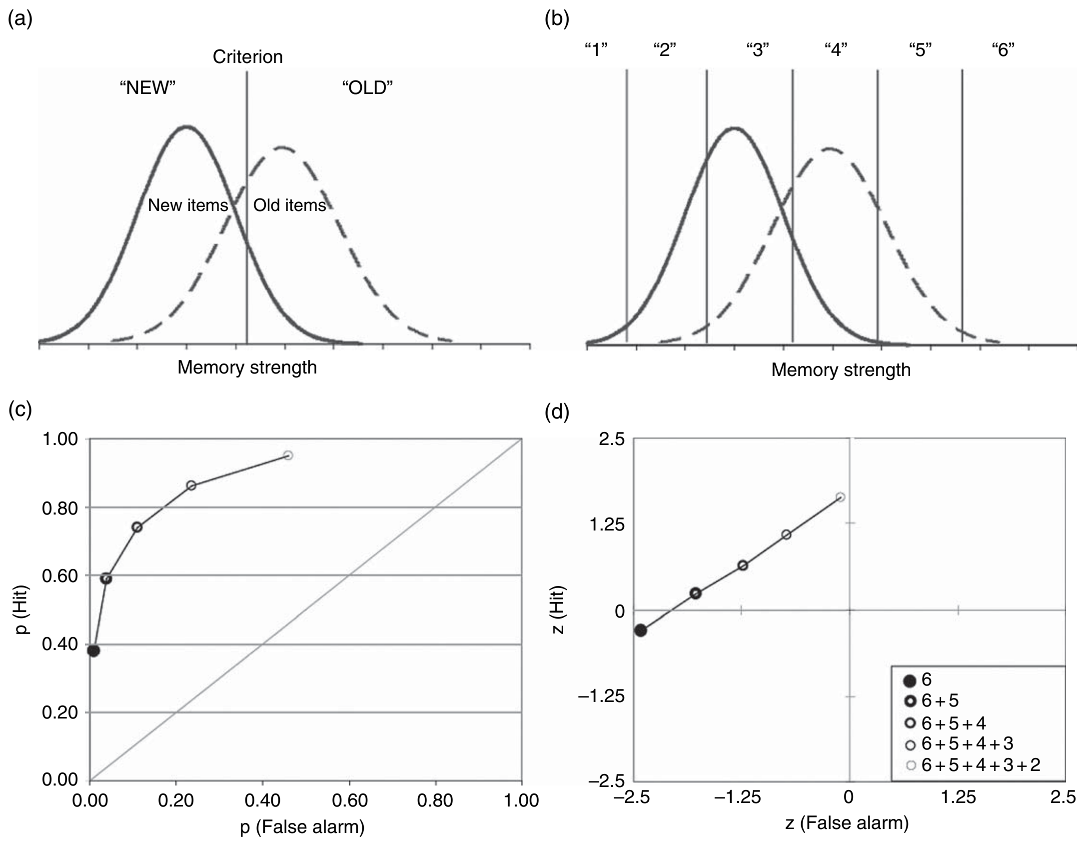


**Figure 1** Example new and old item distributions in (a) a standard binary old/new item recognition paradigm and (b) a confidence rating paradigm for item recognition. Panels (a) and (b) are the same, except for the type of response(s) subjects are required to make. Example ROCs in (c) probability space and (d) z-space. The points in panels (c) and (d) represent pairs of hits and false alarms that are summed across a typical confidence scale ranging from 1 to 6, with 1 labeled 'Sure New' and 6 labeled 'Sure Old.' Thus, the first point represents hits and false alarms for items given a confidence rating of 6 or 'Sure Old.' The next point represents hits and false alarms for items given a confidence rating of 5 and 6, and so on down the confidence scale. Note that the final point (for 1 or 'Sure New') is not plotted because it is constrained to be (1,1).

'Sure Old' (e.g., Sure New 1 2 3 4 5 6 Sure Old). This confidence scale is a way of observing changes in response bias without actually having to manipulate bias experimentally. Thus we can observe how hits and false alarms change as a function of response criteria (i.e., how they change for different ratings on the confidence scale). High confidence ratings correspond to relatively conservative response biases (a low propensity to accept an item as old, or a strict criterion), and low confidence ratings correspond to relatively lax response biases (a high propensity to accept an item as old, or a lax criterion). Thus, subjects are assumed to make decisions by placing n–1 criteria for an n-point confidence along the memory strength axis, as illustrated in **Figure 1(b)** for the standard 6-point confidence scale. An ROC is actually constructed by plotting hit and false alarm pairs (hits on the y-axis, false alarms on the x-axis) beginning with the most confidently recognized items (e.g., hits = P('6'|old), false alarms = P('6'|new)), then repeatedly recalculating the values by including the next most confidently recognized items (e.g., hits = P('6'|old) + P('5'|old), false alarms = P('6'|new) + P('5'|new), etc). Thus, the left-most point on the ROC (**Figure 1(c)**) reflects the hit rate plotted against the false alarm rate when adopting the strictest response criterion (or the least amount of bias). Each subsequent point reflects performance at a more and more relaxed response criterion. Importantly, the function is cumulative, and so both the hits and false alarms are constrained to increase or remain constant as the scoring criterion is relaxed. The example ROC in **Figure 1(c)** shows how each point on the function is calculated from a standard six-point confidence scale. Note that chance performance would be reflected by a function lying on the diagonal (i.e., when hits = false alarms), and increasing accuracy is associated with a function moving toward the upper left, such that the greater the area under the curve, the greater the memory sensitivity or discriminability.

### 2.23.1.2 Why Bother with ROCs?

ROCs have been examined for several reasons. First, given that a subject must adopt some response criterion in order to make an old/new recognition memory judgment, theories of recognition performance must be able to characterize the relationship between accuracy and response criterion, and because ROCs are hit and false alarm rates under different criteria, they provide the opportunity to test a model's characterization of that relationship. Second, ROC results prove to be much more constraining than standard old/new recognition data. That is, memory studies that require subjects to make binary old/new decisions produce an ROC with only one point (a single hit rate and a single false alarm rate). To appreciate the utility of ROC studies, one need only consider how many different theories might account for such a single point – it is difficult to imagine any theory having any difficulty. However, true ROCs – that is, ROCs with multiple points – provide much greater constraint, and thus many fewer theories are able to account for the results. Third, if one can find a theory that adequately accounts for the relationship between accuracy and response bias, then it could be used to derive estimates of accuracy that are not distorted by the particular response criterion that the subject had at a given time. Without such a theory, it may be impossible to determine if an experimental manipulation has influenced accuracy or response bias, or both. So determining which theory can accurately account for ROCs has serious implications not only for theory development, but for measuring recognition memory performance itself.

The shape of an ROC is typically quantified by plotting the z-score (i.e., the inverse of the standard cumulative normal distribution, which assumes a mean of 0 and a standard deviation of 1) of each hit and false alarm rate to produce a zROC (see **Figure 1(d)**). The theoretical motivation for doing so is grounded in signal detection theory as discussed in detail in the sections that follow. Standard linear regression is used to estimate the slope and intercept of the function. If the zROC is linear, then the y-intercept is a rough estimate of recognition accuracy and the slope is an index of the asymmetry of the ROC in probability space. For example, the ROC in **Figure 1(c)** is asymmetrical along the diagonal (it is pushed up on the left side); the slope of the zROC on the right indicates how asymmetrical the ROC on the left is. If the ROC were perfectly symmetrical around the diagonal, the slope of the zROC would be 1.0, but when it is asymmetrical in the way shown in **Figure 1(c)**, the z-slope is less than 1.0. If it were asymmetrical in the other direction it would have a z-slope greater than 1.0, but this is almost never observed in recognition studies. Generally then, the greater the deviation of the slope in z-space from 1.0, the more asymmetrical the ROC is.

Although there are some very stark differences between some of the models reviewed here, and especially between the different classes of models, there are also a few very basic assumptions that they all share. They all assume that recognition decisions require an evaluation of some kind of mnemonic evidence (i.e., memory strength, which may comprise various underlying components depending on the model) that varies for both target and lure items. Thus, all the models are depicted in terms of their probability density distributions of memory strength for target and lure items, such as those shown in **Figures 1(a)** and **1(b)** (which show an unequal-variance signal detection model). The x-axis always represents memory strength (or 'evidence,' more generally), and there will always be at least two probability distributions along that axis corresponding to the lure and target items (although sometimes more axes are introduced, and not all distributions necessarily lie along the same axes).

The models we review in this chapter all make predictions about the shape of zROCs. Therefore, the shape of zROCs found in different types of recognition tests serve as the real tests of the models we consider – that is, the primary question is whether a model is capable of predicting (or at least explaining) the shapes that ROCs and zROCs take on under the experimental conditions devised thus far. First, for each class of models, we review the most prominent models to date and their ROC/zROC predictions, with an eye toward understanding why the models make the predictions that they do. After describing the models and their predictions in each class, we then briefly review the empirical ROC and zROC findings, indicating which models have been best supported by data thus far.

## 2.23.2 Evaluating Theories of Recognition

Theories of recognition fall into three general classes: threshold, signal detection, and hybrid models (i.e., models including both threshold and signal detection assumptions). In the following sections, we describe the core assumptions of these theories, focusing on the most frequently used models within each class, and evaluating their ability to account for recognition data.

## 2.23.3 Threshold Models

Threshold theories are one of the simplest classes of recognition memory models, and they motivate the common practice of estimating memory accuracy by subtracting false alarms from hits. Although their origins are obscure, they can be traced back to the psychophysical work of Fechner (see Boring, 1929), in which it was proposed that there is some minimum sensory signal strength (i.e., the 'threshold' or 'limina') that must be attained before a subject is able to perceive a stimulus. Threshold models treat memory as probabilistic in the sense that only some proportion of the items will exceed the threshold. Thus, for all threshold models, memory is described essentially in terms of success and failure; there is some probability with which memory will succeed (strength exceeds the threshold) and some probability with which memory will fail (strength falls below the threshold).

### 2.23.3.1 High-Threshold Model

The high-threshold model (HT) is perhaps the simplest threshold model (see **Figure 2**) and is the one that is assumed when subtracting false alarms from hits to measure accurate recognition performance. It assumes distributions of old and new items, with old items falling farther to the right along the strength axis than new items. Note that the distributions for HT models are often represented as rectangular for the sake of simplicity, but they can actually take on various different shapes (see Macmillan and Creelman, 2005). The threshold is the point at which the old item distribution exceeds the new item distribution. The new item distribution falls below the threshold, suggesting that new items are never truly remembered in the same sense that old items are. The proportion of old items above the threshold is the probability $R_T$. Memory decisions are made by selecting some level of memory strength as a response criterion and accepting items that exceed that level of strength as having been studied. If the response criterion is set exactly at the threshold, then the hit rate will be equal to $R_T$, and the false alarm rate will be zero. For any given experimental condition the threshold is fixed, but the response criterion is free to vary in either direction of the threshold so the hit rate may exceed $R_T$ (with a lax criterion) or may be less than $R_T$ (with a strict criterion).

Critically, as the response criterion is relaxed (i.e., shifted to the left of the threshold), the hit rate and false alarm rate will increase at a constant rate until they reach 1.00, producing a linear ROC like that seen in **Figure 2**. When a linear ROC is plotted on z-coordinates, the resulting zROC is actually U-shaped. Thus, assessing the linearity of empirical ROCs and z-ROCs provides a direct test of this

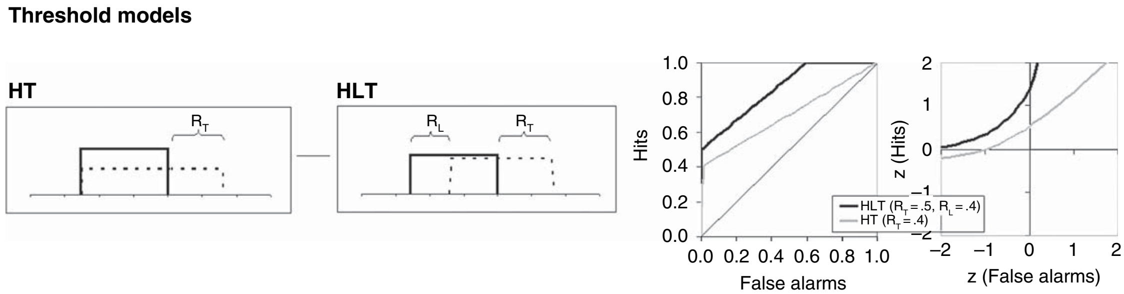


**Figure 2** Strength distributions and predicted ROCs and zROCs for the high threshold (HT) and high-low threshold (HLT) memory models. Predicted ROCs on the left are plotted in probability space, and the ROCs on the right are plotted in z-space. Adapted from Yonelinas AP and Parks CM (2007) Receiving operator characteristics (ROCs) in recognition memory: A review. *Psychol. Bull.* 133: 800–832, with permission.

threshold model. Moreover, the model predicts that as performance increases the ROC should become more asymmetrical. That is, as memory increases, the left y-intercept will increase, and thus the slope of the ROC (and the z-ROC) will decrease.

### 2.23.3.2 High-Low Threshold Model

The high-low threshold (HLT) model is another common threshold model (sometimes referred to as the 'two-high threshold' or the 'double-high threshold' model), in which a second memory component is added to represent the probability that new, or lure, items can be recognized as new ($R_L$, e.g., "I would have remembered my name if it had been in the study list"). The HLT model is identical to the HT model except that the new item distribution extends further to the left than the old item distribution, creating a second threshold, which old, or target, items cannot cross (see **Figure 2**). The low threshold falls at the left-most point of the old item distribution, such that any new item falling below this threshold can be recognized as a new, or lure, item. As with the other threshold, the fact that old items cannot cross the low threshold suggests that they cannot be recognized as new in the same sense that truly new items can be. Although there are two thresholds, a single criterion is used in a typical old/new recognition experiment, just as it would be in the HT model (and in an ROC experiment, there would be the usual n–1 criteria for an n-point scale).

The HLT model generates ROCs very similar to those generated by the HT model, except that the right end of the ROC moves up and intersects the upper x-axis at a point that is $R_L$ from the 1,1 intercept (see **Figure 2**). Thus, like the HT model, the HLT model predicts linear ROCs that are U-shaped in z-space, but it is not constrained to generate an asymmetrical ROC. In fact, the degree of ROC asymmetry can vary independently of overall performance. If $R_T$ is greater than $R_L$, then the ROC will have a slope less than 1; if $R_T$ is less than $R_L$, then it will have a slope greater than 1; and if the two parameters are equal, then the ROC slope will be equal to 1 (i.e., a symmetrical ROC).

Although the HT and HLT models predict linear ROCs, it is possible to produce various nonlinear ROCs by introducing additional parameters or thresholds. For example, Luce (1963) proposed a 'two-state high-threshold' model that produces an ROC made up of two joined linear segments (also see Green, 1960; Norman and Wickelgren, 1965). In fact, by adding multiple steplike thresholds or decision rules, one can produce an ROC that is effectively curvilinear (e.g., Krantz, 1969; Buchner et al., 1995; Malmberg, 2002). However, the latter approach is rarely adopted because it requires an additional free parameter for each new threshold (Hilford et al., 2002). Nonetheless, a consideration of these models is important because it shows that, although ROC experiments may prove useful in testing specific threshold models, results that disconfirm one threshold model may not be problematic for another. Here, we focus on the HT and HLT models because they are the two most commonly adopted threshold models.

There is one important caveat about using tests of linearity to assess the threshold models. Technically, the HT and HLT models (and models in which these theories are nested, such as some of the dual-process models discussed later) predict ROCs that are kinked at their extremes. That is, for both models, the ROC is linear until it intersects the y-axis, at which point it is forced to drop and approach the 0,0 intercept (see **Figure 2**). This occurs when the response criterion moves to the right of the threshold (the high one for HLT), so that false alarms are at zero and the hit rate drops as the criterion becomes more and more strict (i.e., moves further to the right). For the HLT model, the same will also occur as the response criterion becomes very lax (i.e., moves to the left) – that is, the hit rate will reach 1.0 before the false alarm rate, and the false alarms will continue to increase until they reach 1.0 as well. This means that, if the extreme points on an ROC approach floor or ceiling levels, the ROC might appear curvilinear, even if it is perfectly predicted by a threshold model. Thus, when assessing threshold-based models it is important to determine if the extreme points in the average ROC, as well as the individual subject ROCs, are approaching floor or ceiling levels. In these cases, an evaluation of ROC linearity may not provide a valid assessment of threshold models.

Threshold theory, as a general class of models, has one core assumption: there is a sensory limit or threshold. With respect to memory, this means that, although there is a strength continuum, memory can fail. However, additional assumptions have sometimes been adopted by different theorists. Although these auxiliary assumptions do not always alter the predictions that the models make, in some cases they do. One very common assumption is that only old items can exceed the high threshold. This assumption is made in both the HT and HLT models (see **Figure 2**). Thus, the models assume that only items that have been studied can exceed the upper threshold, and that false alarms arise because the response criterion is set to the left of the threshold (likewise, only lures can cross the low threshold in the HLT model). In contrast, however, Luce's (1963) threshold model allows a portion of the new item distribution to exceed the high threshold, and thus it allows for the possibility that false alarms might arise even when the response criterion falls to the right of the threshold.

Second, it is sometimes assumed that the threshold marks a discrete boundary between conscious and nonconscious memory. For example, Fechner suggested that items falling below the threshold are not consciously perceived (i.e., they are subthreshold or subliminal) (as discussed in Boring, 1929). This assumption leads to the expectation that asking subjects to report when they are truly remembering a test item, or if they know it was studied on the basis of familiarity, such as in Tulving's (1985) remember/know (RK) procedure, might provide a way of determining the subject's memory threshold (e.g., Yonelinas and Jacoby, 1995). Thus, the $R_T$ parameter (i.e., the left y-intercept of the ROC) might correspond to the proportion of remembered items. Alternatively, the threshold may correspond to the distinction between know and new responses, if both remember and know responses are treated as forms of conscious memory. In any case, the consciousness assumption has not been widely accepted, and many discussions of threshold theory – particularly those that appeared during the 1960s and 1970s – make no direct mention of conscious experience. Thus, even if a threshold does exist, subjects may not be able to determine exactly what level of memory strength corresponds to this threshold.

Third, it is sometimes assumed that memory strength is all-or-none in the sense that items are either in a discrete and homogeneous 'remembered' state, or they are in a distinct and mutually exclusive 'not remembered' state. Indeed, the typical equations of threshold theory represent memory as a simple probability, which is sometimes interpreted as indicating that all remembered items must be alike because there is no representation of the variance in memory strength. The implication of this assumption is that subjects either remember everything about an event or they remember nothing about the event. If this were true, though, it is not clear how subjects could make meaningful confidence judgments. For instance, if threshold theory is a state theory (the idea the there are mutually exclusive, discrete, homogeneous states of memory), the depiction of threshold theory in **Figure 2** and its description here would be misleading. In the figure, the x-axis would not represent strength, or if it did, then there would be no true distribution of items along that axis. Moreover, memory decisions would not be made by setting criteria based on different strengths, as different strengths would not exist. Instead, subjects would be forced into the awkward situation of randomly responding with different levels of confidence despite their experience of a uniform level of familiarity (and hence confidence) for all remembered items. As Wickelgren put it:

> If a subject truly had only two states in his [memory] system and were faced with the problem of choosing one of six rating responses, the subject would either think the experiment or the experimenter was pretty stupid, or else that there was something wrong with him or his understanding of the task. In either case, it is not clear what his decision rule would be. (Wickelgren, 1968: 129; but see Krantz, 1969, for an alternative view)

Thus, if threshold theory is indeed a state theory, it may not be useful to use confidence-based ROCs as a means of testing it. However, various theorists, including Fechner, have argued that sensation strength can vary continuously and be subject to a threshold (e.g., Fechner as described in Boring, 1929; Swets, 1961; Krantz, 1969), and confidence-based ROCs have been used extensively to test the threshold models (but see Malmberg, 2002, for an argument concerning the usefulness of ROCs in deciding between continuous and state theories). So although the all-or-none assumption is sometimes adopted, it is not a necessary assumption of threshold theory in general.

Fourth, threshold theory is sometimes interpreted as indicating that there is a non-mnemonic process such as 'random guessing' or 'noise' that contributes to performance in addition to a true memory retrieval process (e.g., Batchelder and Riefer, 1990). The idea is that if an item's strength exceeds the threshold, then memory is successful and the item will be remembered, whereas if its strength falls below the threshold, then memory fails and the item will not be remembered. In the latter case, the item might still be accepted as old on the basis of some non-mnemonic process such as a guess or a response error. Although it seems reasonable that subjects might guess or make response errors, the proposal that these errors are due solely to such non-mnemonic processes is not a necessary assumption of threshold theory in general. That is, all responses could be based on memory strength, but because the old and new item distributions can be completely overlapping at points below the threshold, accepting items below the threshold becomes functionally equivalent to guessing or random responding.

### 2.23.3.3 Evaluation

The threshold models provide a poor account of recognition memory. This evaluation is based on their predictions of linear ROCs and U-shaped zROCs. First, in tests of item recognition there is no evidence for the threshold that serves as the core of threshold theory. That is, item ROCs are not linear as predicted by the models, but are instead curvilinear and have an inverted U shape. This pattern was first reported by Egan (1958) (see **Figure 3**) and has now been observed in countless experiments (for earlier discussions of this finding see Egan, 1958; Murdock, 1974; Ratcliff et al., 1992, 1994; Glanzer et al., 1999). Moreover, item recognition ROCs are linear when plotted in z-space, in contrast to the U-shaped zROCs predicted by the threshold models. Although slight deviations from linearity in z-space have been reported in item recognition studies (e.g., Ratcliff et al., 1994; Yonelinas, 1997, 1999a; Heathcote, 2003), the zROCs are almost never as U-shaped as the threshold models predict.

There are, however, some aspects of the ROC data that are consistent with the threshold notion. For example, the HT model predicts that as performance increases the ROCs should become more asymmetrical (z-slopes should drop), and there are variables, such as levels of processing and list length, that do result in this pattern (see **Figure 4**; e.g., Yonelinas et al., 1996; Glanzer et al., 1999). However, other manipulations,

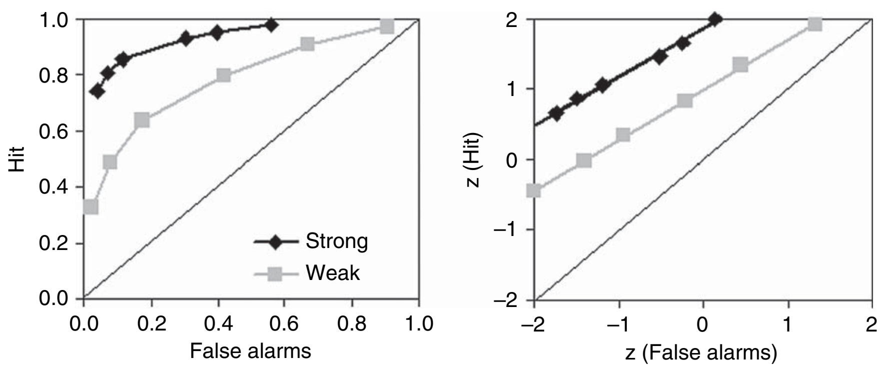


**Figure 3** Item recognition ROCs for weak (one presentation) and strong (two presentations) items plotted in probability space (on the left) and in z-space (on the right). The figure illustrates that item ROCs are (a) curved downward in probability space, (b) linear in z-space, and (c) asymmetrical along the chance diagonal and thus (d) they have a slope in z-space of less than 1.0. Further, the slopes of the two zROCs are the same, but sensitivity differs between conditions. From Experiment 1 (Figure 20) in Egan JP (1958) Recognition memory and the operating characteristic. *USAF Operational Applications Laboratory Technical Note.* No. 58–51: 32. Hearing and Communication Laboratory, Indiana University.

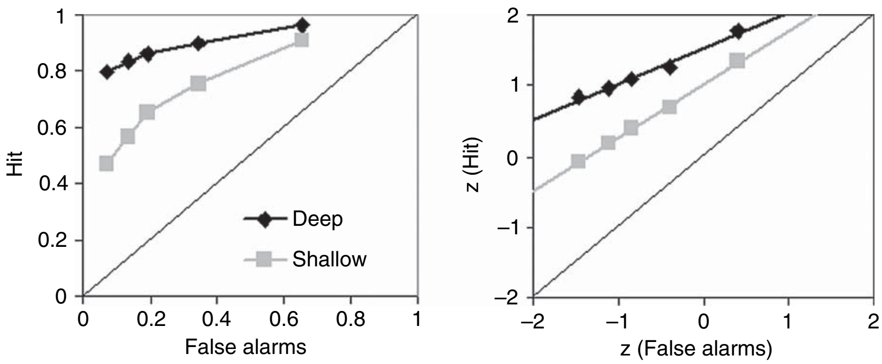


**Figure 4** Item recognition ROCs and z-ROCs for items encoded deeply or shallowly. Both the z-slope and sensitivity differ between conditions. From Experiment 1, Yonelinas AP, Dobbins I, Szymanski MD, Dhaliwal HS, and King L (1996) Signal-detection, threshold, and dual-process models of recognition memory: ROCs and conscious recollection. *Conscious. Cogn.* 5: 418–441.

such as study repetition, increase performance but do not affect symmetry (e.g., Glanzer et al., 1999), which presents problems for the HT model. However, the HLT model, which includes two thresholds and so can vary the degree of asymmetry independently of overall performance, is consistent with these aspects of the recognition results.

In addition, linear ROCs have been reported in several studies of relational recognition tasks, such as test of source or associative recognition (e.g., Glanzer et al., 1999; Yonelinas, 1999a; Rotello et al., 2000; Arndt and Reder, 2002). These linear ROCs are consistent with the threshold predictions and suggest that, at least in relational tests, subjects do sometimes fail to retrieve the relevant information altogether (i.e., items fall below threshold). In direct contradiction to threshold theory predictions, though, curved ROCs have also been reported in other relational recognition experiments (e.g., Yonelinas, 1999a; Qin et al., 2001), and therefore these models do not provide an adequate account of relational recognition performance either.

There are various other ROC results discussed in the following sections that present additional problems for the threshold models, but the item and relational ROC results noted here have led most researchers to reject the threshold models as viable accounts of recognition memory.

## 2.23.4 Signal Detection Models

Signal detection theory (e.g., Tanner and Swets, 1954; Swets et al., 1961) is a statistical decision model that has been applied to studies of item recognition (e.g., Egan, 1958; Murdock, 1965; Parks, 1966; Banks, 1970) and source recognition (e.g., Marsh and Bower, 1993; Hoffman, 1997). In item recognition tasks, it is assumed that studied items have greater memory strength than nonstudied items, but there is variability in memory strength such that the old and new items form overlapping Gaussian (or normal) distributions as in **Figure 5**. The distance between the old and new distributions measured in z-scores is *d′*, which represents how much stronger the studied items are than the new items. Recognition decisions in standard old/new tests are made by setting a response criterion equal to some level of memory strength and responding ‘old’ only to items exceeding that criterion; in confidence-rating tests, decisions are made by placing n–1 criteria along the memory strength axis for an n-point confidence scale.

The core assumption that all pure signal detection models share is that the strength distributions of old and new items are normal (or Gaussian) in shape. The Gaussian shape of these distributions gives rise to curved ROCs that are perfectly linear when plotted in z-space, and thus the linearity of empirical zROCs can be used to test this assumption (see **Figure 5**). The reason Gaussian distributions produce curvilinear ROCs is because changes in response criteria result in disproportional changes in the hits and false alarms. When the response criterion starts off as strict (very far to the right), changes (moving to the left) will have large effects on the proportion of the old item distribution that will be recognized, but relatively modest effects on the proportion of the new item distribution that will be recognized. In contrast, as the response criterion

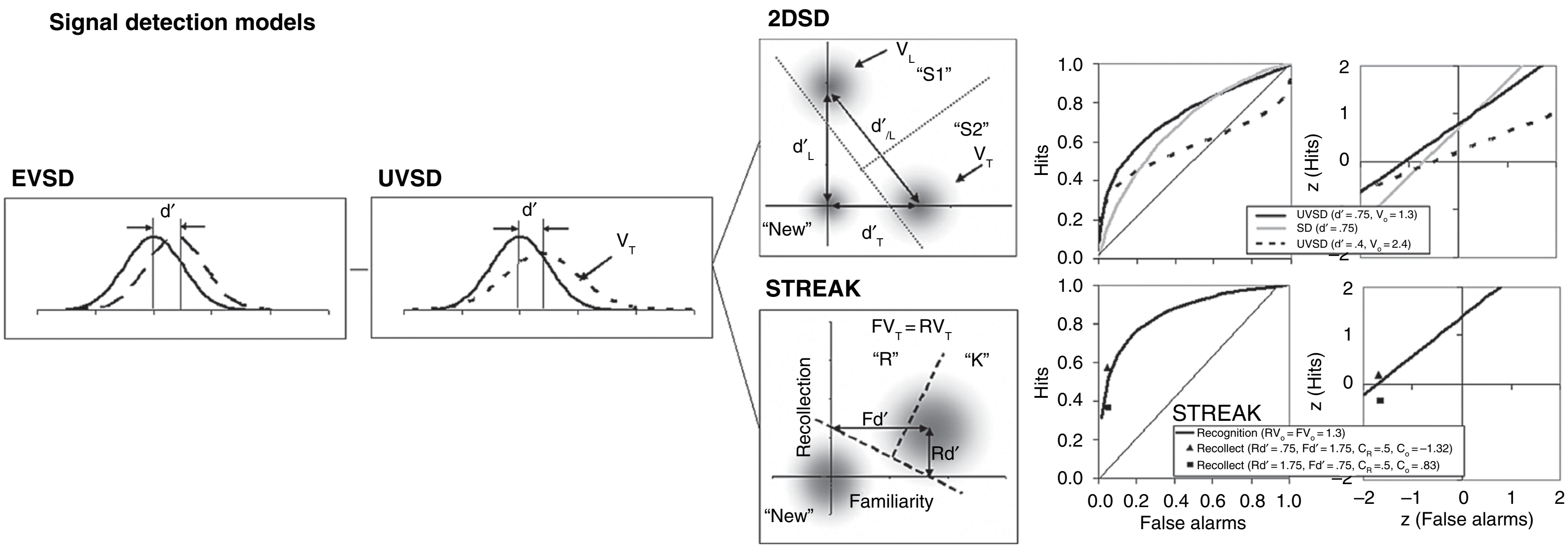


**Figure 5** Strength distributions and predicted ROCs and zROCs for the signal detection models, including the equal-variance signal detection (EVSD), unequal-variance signal detection (UVSD), two-dimensional signal detection (2DSD), and sum-difference theory of remembering and knowing (STREAK) models. Predicted ROCs on the left are plotted in probability space and the ROCs on the right are plotted in z-space. Adapted from Yonelinas AP and Parks CM (2007) Receiving operator characteristics (ROCs) in recognition memory: A review. *Psychol. Bull.* 133: 800–832, with permission.

becomes more and more lax, changes will have larger effects on the proportion of new items that are recognized and decreasing effects on the proportion of old items that are recognized. Thus, the slope of the ROCs starts off very steep, but then starts to decrease and eventually levels out as the false alarm rate increases, leading to a curvilinear ROC.

The primary theoretical difference between the signal detection models and the threshold models is that the signal detection models assume that memory can never truly fail. That is, signal detection models assume that there is a memory signal that always provides some useful information. Therefore, signal detection models eschew the idea that memory is probabilistic (i.e., it succeeds or fails) and instead treat memory as deterministic, meaning that there is a memory signal for every item encountered – or essentially, that memory is always successful, even if it does not always return a strength value that leads to an accurate response.

#### 2.23.4.1 Equal-Variance Signal Detection Model

The equal-variance signal detection (EVSD) model is the simplest signal detection model (see **Figure 5**), because it includes only one parameter – the accuracy measure $d'$, the difference in average strength of the new and old item distributions. The model assumes that the variance of the targets' strengths is equal to that of the lures. Because the old and new distributions are assumed to have the same shape, the model generates a symmetrical ROC that has a slope of 1.0 in z-space. Thus, assessing the slope of the zROC provides a direct test of the equal-variance assumption.

Although the core assumptions underlying the EVSD model are the Gaussian and equal-variance assumptions, a number of auxiliary assumptions have sometimes been adopted. For example, many theories have assumed that the memory signal reflects a continuous scalar index of memory strength or familiarity (e.g., global memory models such as TODAM (Murdock, 1993) and SAM (Gillund and Shiffrin, 1984)). Alternatively, the memory signal could also reflect how many different aspects or features of the test item are remembered, or it may reflect the products of two or more separate memory processes such as recollection and familiarity (e.g., Johnson et al., 1993; Wixted and Stretch, 2004; Wixted, 2007). Another assumption, which is often adopted in order to account for subjective reports of remembering and knowing (Tulving, 1985), is that remember responses simply reflect stronger or more confident memories than know responses (e.g., Donaldson, 1996; Hirshman and Master, 1997; Dunn, 2004). Thus, when RK scores are plotted in ROC space they should fall along the same symmetrical ROC that is expected in item recognition, with the remember point (i.e., the proportion of correct remember responses vs. the proportion of incorrect remember responses) falling to the left of the recognition point (i.e., remember plus know responses).

#### 2.23.4.2 Unequal-Variance Signal Detection Model

The unequal-variance signal detection model (UVSD) is probably the most common signal detection model of memory (see **Figure 5**), and it includes a distance measure between the means of the two distributions (similar to $d'$; see Wickens, 2002; Macmillan and Creelman, 2005, for details on accuracy measures for the unequal-variance model), as well as a second component: the variance of the old item distribution relative to the new item distribution ($V_T$). If the old item variance is greater than that of the new distribution, then the ROC will appear to be pushed up on the left side, as in **Figure 5**. If the old item variance is less than that of the new item distribution, the ROC will be pushed up on the right side (this is not illustrated, and it is rarely observed). Like the EVSD model, the UVSD model predicts curved ROCs that are linear when plotted in z-space. However, because the old item variance can vary, the model can produce asymmetrical ROCs (i.e., slopes in z-space greater or less than 1.0) – thus the variance parameter can also be thought of as a symmetry parameter, because it is the $V_T$ parameter that makes an ROC symmetrical or asymmetrical. The inclusion of separate parameters for sensitivity and symmetry also suggests that the two memory components might be experimentally dissociable. That is, there may be variables that influence $d'$ while leaving $V_T$ unaffected, whereas other variables might influence $V_T$ while leaving $d'$ unaffected. However, the UVSD model does not indicate which experimental variables might produce such dissociations.

One property of the UVSD model that is often overlooked (although see Green and Swets, 1966; Decarlo, 2002) is that, if the variance of the old item distribution is greater than that of the new item distribution, the model can predict a curved ROC that drops below the chance diagonal (see **Figure 5**).

This will happen when the old item variance becomes large, and some portion of the old distribution falls farther to the left than the new distribution. Psychologically, this means that the encoding phase must have decreased, rather than increased, the memory strength of some of the studied items.

The UVSD model does not specify why the old and new variances differ, or why the old item variance almost always exceeds the new item variance (see the section titled 'Evaluation' that follows), but one common assumption is that the old distribution is more variable because of encoding variability (e.g., Hilford et al., 2002; Wixted, 2007). That is, because encoding will likely increase the strength of some items more than others, the old item distribution will be more variable than the new item distribution. Such an account predicts that the ROCs should be asymmetrical such that the z-slopes are less than 1, rather than being equal to or greater than 1. Although the encoding variability explanation seems intuitively logical and, therefore, a potentially good account of increased old-item variability, it is not technically consistent with the UVSD model. The encoding variability hypothesis describes differences in how much items increase in memory strength as a result of study, but, quite logically, does not allow for decreases. Thus, encoding variability *per se* does not lead to the expectation that the ROC should drop below the chance diagonal, as will happen whenever the old item variance exceeds the new item variance (although this is most evident when the slope gets very low).

As with the EVSD model, one can potentially explain RK reports by assuming that remember responses simply reflect high-confidence recognition responses (e.g., Donaldson, 1996; Hirshman and Master, 1997; Wixted and Stretch, 2004). The UVSD model accordingly predicts that the RK data should fall on the same function that is observed in recognition ROC studies. In contrast to the EVSD model, however, the recognition ROC can be asymmetrical.

#### 2.23.4.3 Two-Dimensional Signal Detection Model

The two-dimensional signal detection model (2DSD) is an extension of the UVSD model that is aimed at explaining performance on source recognition tests (Hilford et al., 2002; Glanzer et al., 2004; for earlier development of multidimensional signal detection models see Tanner, 1956; Macmillan and Creeman, 1991; Ashby, 1992; Banks, 2000). In this model, there are two memory strength axes or dimensions (hence the name two-dimensional), one for each source. Therefore the distribution of strengths for items presented in Source A lies along the Source A dimension, and the strength distribution for items presented in Source B lies along the Source B dimension (see **Figure 5**). New items in the recognition test lie at the intersection of these two dimensions, and therefore there is a triangular relationship between the three distributions. The model assumes that studying items in one source will increase the items' strength along that source axis in the same way that study increases average strength in the EVSD and UVSD models (e.g., study of items in Source A will push the distribution up the Source A dimension). Note that the depiction of the model in **Figure 5** has transformed a model that exists in three dimensions (i.e., in the x, y, and z planes) into a two-dimensional illustration of the model viewed from the top. The 2DSD illustration **Figure 5** is similar to a topographical map because it is assumed that one is looking down at the model. There is an unseen axis (the y-axis) for the height of the distributions that would rise from the intersection of the two illustrated axes, and the circles actually represent three-dimensional Gaussian distributions (see Wickens, 2002; Macmillan and Creelman, 2005, for good introductions to multidimensional signal detection models). Although it is not illustrated, there is actually some overlap between the distributions lying along the two axes, as well as some overlap with the new item distribution.

The 2DSD model includes five free parameters – the strength and variance of each of the old item distributions relative to the new item distribution (with items from one source arbitrarily treated as targets and items from the other as the lures: target strength ($d'_T$), target variance ($V_T$), lure strength ($d'_L$), and lure variance ($V_L$)), as well as the distance between the two source distributions ($d'_{T/L}$). The target strength and lure strength refer to the distance between each source distribution and the new item distribution, thereby providing measures of item recognition for items from each source. The distance between the two source distributions is the measure of source recognition performance. Although the two source dimensions are presented as orthogonal in **Figure 5**, the angle is generally expected to be much less than 90° to account for the observation that people are more accurate in item than in source recognition (i.e., the distance between the two source distributions is typically shorter than between either of those distributions and the new item distribution). In general, there are not enough data points available in ROC studies to allow the degree of this angle to be estimated, but it could in principle be allowed to vary as a means of measuring the relationship between source and item performance; however, this would require a novel source memory paradigm (e.g., Banks, 2000).

The 2DSD model assumes that people make item recognition decisions by setting a criterion that runs between the new item distribution and both of the old distributions (the diagonal line that runs from the upper left to the lower right in the 2DSD illustration in **Figure 5**). Source recognition decisions are made by setting another criterion that runs perpendicular to the item criterion and runs between the two old source distributions (the diagonal running from the upper right to the lower left).

In addition to the core assumptions of the UVSD model, the 2DSD model makes two further assumptions, one of which is simply that there are two dimensions of strength, one for each source. In addition, the model assumes that item and source judgments are based on the same underlying strength distributions and therefore predicts that performance on these tasks should be directly related. That is, manipulations that increase source recognition will also necessarily increase item recognition. Note, however, that the model does not predict exactly how closely item and source recognition will be related – that relationship will depend on the angle between the two source dimensions and the types of source information that the subject brings to bear when making the item discrimination.

The 2DSD model makes the same ROC predictions as the UVSD model. That is, because the model is based on Gaussian strength distributions, it predicts that ROCs (both item and source) should be curved in probability-space and linear in z-space. Because the model includes free parameters for the variance of the old item distributions, it can produce item recognition z-ROCs with slopes less than 1, and it can produce dissociations between ROC accuracy and asymmetry.

#### 2.23.4.4 Sum-Difference Theory of Remembering and Knowing

The sum-difference theory of remembering and knowing (STREAK) is another two-dimensional extension of the UVSD model (see **Figure 5**; Rotello et al., 2004). The STREAK model was proposed to account for RK and item recognition ROC results. In a typical RK paradigm including remember, know, and new responses, an ROC can be constructed from two points: the remember hit and false alarm pair (which will be the lower left point on the ROC) and the remember + know hit and false alarm pair (also referred to as the ‘recognition’ point because it includes all recognized items). Adding in the ‘new’ responses would result in a point constrained to be (1,1). This is the same technique used to construct ROCs from confidence scales. The STREAK model assumes that one dimension of memory strength represents global familiarity and the other dimension represents the memory strength associated with recollection of specific details associated with an item. Every item, old or new, is assumed to have both recollection and familiarity strengths (indexed as R$d'$ and F$d'$, respectively), but the old items are expected to have higher strengths than the new items, on average. There are two distributions, corresponding to old and new items. New items lie at the intersection of the familiarity and recollection axes, and the old item distribution can occupy any space between the two axes (technically it can move beyond those axes as well, but that would indicate negative memory along one or both dimensions). Strength on each dimension is represented by the distance of the peak of the distribution from the axes. Thus, recollection strength is the distance of the peak of the distribution (the center of the circle in the STREAK illustration in **Figure 5**) from the recollection axis, and familiarity strength is the distance from the familiarity axis. The old item distribution is assumed to have greater variance than the new item distribution. In fact, in order for the model to be identifiable in standard RK experiments the new item variance is set at 80% of the old item variance (this approximates z-slopes of .80, the average slope found in item recognition). In confidence-based ROC studies, though, or studies in which both RK and confidence responses are collected, the old item variance is treated as a free parameter ($V_T$). Overall, then, the model has either two or three parameters, depending on whether $V_T$ is allowed to vary or not.

STREAK assumes that people make item recognition decisions by setting a response criterion between the new and old item distributions that runs parallel to the line that would intersect the R$d'$ and F$d'$ values on their respective axes (this criterion is shown actually intersecting those points in **Figure 5**). RK decisions are made by selecting a second response criterion, which runs perpendicular to the old/new criterion, that is used to determine if the item is more remembered or more familiar. Although not evident in the illustration of the model, the sum of the recollection and familiarity strength values dictates whether a person makes an old or new response (if recollection + familiarity > old/new criterion, 'old'), whereas the difference between the two strength values is used to make the RK response (if recollection − familiarity > RK criterion, 'remember'). Conceptually, STREAK treats standard item recognition in the same way as the UVSD model, but with 'memory strength' interpreted as the sum of recollection and familiarity strengths (see also Wixted, 2007, for a similar assumption in a UVSD model). In addition, the STREAK model assumes that recollection and familiarity lie along a single continuum and that people simply select a criterion between the two extremes in order to respond in RK experiments. This model differs markedly from the other signal detection models in that it explicitly assumes that two processes underlie recognition memory and produce the components that make up 'memory strength.'

Because the model is based on Gaussian strength distributions, it predicts curved item ROCs that are linear in z-space, like the UVSD model. If the $V_T$ parameter is fixed at .80 (the new-to-old item variance ratio), it predicts asymmetrical ROCs with z-slopes of .80. However, if $V_T$ is treated as a free parameter, then the item recognition process becomes identical to that of the UVSD model. The unique aspect of this model, however, is that because RK judgments are based on different decision rules than old/new judgments, the model can produce RK z-slopes that differ from the ROC z-slopes. That is, the model can produce a remember ROC point that can fall below, above, or along the regular item ROC, whereas the remember + know point has to fall exactly on the confidence ROC because it corresponds to all the items exceeding the old/new response criterion (see Figure 5). In this way, the RK-slope (i.e., the line joining the remember point to the recognition point to the right) can be greater, less than, or equal to that of the ROC slope.

### 2.23.4.5 Evaluation

The core assumption of all the signal detection models (i.e., the Gaussian assumption) is generally supported in tests of item recognition; that is, item ROCs have an inverted U shape in probability space and are approximately linear in z-space (e.g., Figures 3 and 4), a pattern that has been demonstrated repeatedly over the course of approximately 40 years. The EVSD model fails to account for the fact that z-slopes are less than 1 in item recognition, but all other signal detection models (which allow variance to differ between the targets and lures) account for this finding easily.

However, the results of relational recognition experiments present a challenge to all the signal detection models. ROCs in relational recognition tests can be either linear or curvilinear in probability space, but unlike item recognition, they are almost always U-shaped in z-space. For example, Figure 6 presents associative ROCs for word pairs along with item ROCs for single words (Experiment 3 from Yonelinas, 1997). The item ROC is significantly concave in probability space and does not differ significantly from linear in z-space. Conversely, the

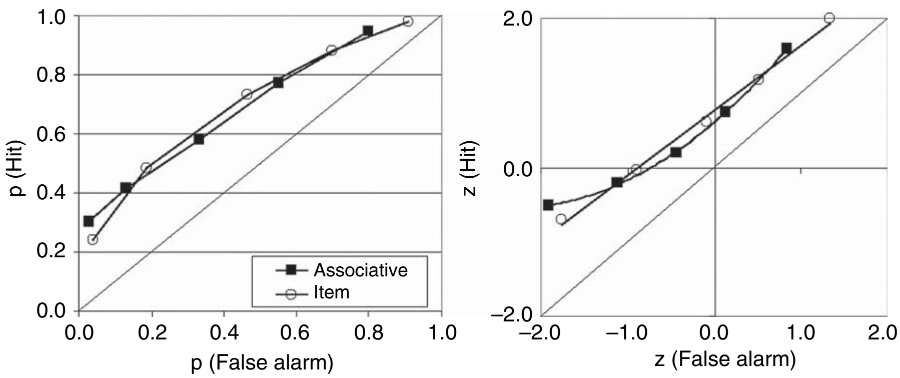


**Figure 6** Item and associative recognition ROCs. The item ROC is concave in probability space and linear in z-space, whereas, the associative ROC is linear in probability space and convex in z-space. From Experiment 3 in Yonelinas AP (1997) Recognition memory ROCs for item and associative information: The contribution of recollection and familiarity. *Mem. Cognit.* 25(6): 747–763.

associative ROC is linear in probability space and convex in z-space. Similar findings have been reported in other associative recognition studies (e.g., Yonelinas et al., 1999; Kelley and Wixted, 2001; Healy et al., 2005), in tests of source recognition (Yonelinas, 1999a; Slotnick et al., 2000; Hilford et al., 2002; Decarlo, 2003; Glanzer et al., 2004; Slotnick and Dodson, 2005), and in plurality reversed recognition tests (e.g., Rotello et al., 2000; Arndt and Reder, 2002). In fact, the regularity of the U-shaped zROCs across relational studies is quite striking. In 52 out of 59 conditions taken from 17 studies of relational recognition the quadratic coefficient was positive (Parks and Yonelinas, 2007). (The quadratic coefficient is the term of a polynomial regression equation that quantifies the degree of U-shaped curvature in a function. Positive quadratic coefficients indicate that the function is U-shaped, negative quadratic coefficients indicate that it has an inverted U shape, and 0 indicates that there is no U-shaped curvature.) Thus, the vast majority of the relational recognition studies have resulted in U-shaped zROCs. U-shaped zROCs directly contradict the Gaussian assumption of the signal detection models, and therefore indicate that they are unable to account for these data.

Although relational recognition presents a serious challenge to the signal detection models, the models are able to account for other types of recognition data, though of course some models perform better than others. The worst is the EVSD model, which can only account for inverted-U-shaped ROCs and fails to account for any other of the common findings in the recognition ROC literature. The other models, however, have had some success in accounting for some aspects of RK studies. The UVSD and 2DSD models can make the auxiliary assumption that RK responses are just confidence responses split into two categories, with 'remember' reflecting high and 'know' reflecting low confidence. Thus, the models predict that the remember and remember + know points should fall along the same ROC produced by confidence ratings. In fact, studies that have directly compared RK and confidence responses have shown that RK scores and confidence judgments typically fall along the same ROC. For example, **Figure 7** shows remember, and remember + know responses plotted along with confidence-based ROCs from the same subjects (the top function is from Experiment 1 of Wixted and Stretch (2004), and the bottom function is from Experiment 1 of Yonelinas et al. (1996)). As can be seen in **Figure 7**, the RK points fall along the same functions that fit the confidence

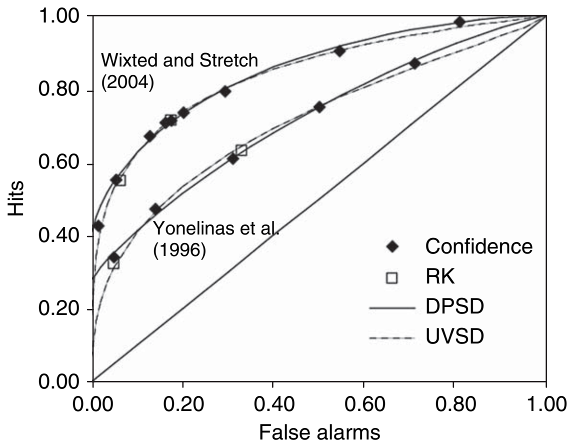


**Figure 7** Confidence ROCs and RK ROCs from Wixted JT and Stretch V (2004) In defense of the signal detection interpretation of remember/know judgments. *Psychon. Bull. Rev.* 11: 616–641 and from Yonelinas AP, Dobbins I, Szymanski MD, Dhaliwal HS, and King L (1996) Signal-detection, threshold, and dual-process models of recognition memory: ROCs and conscious recollection. *Conscious. Cogn.* 5: 418–441. The figure illustrates that when subjects make RK and confidence responses to each test item, the RK ROC points fall along the same function as the confidence ROC. The figure presents the fits of the DPSD and UVSD models and indicates that both models fit the empirical data quite well.

ROCs. Wixted and Stretch (2004) reexamined several previous studies that had collected RK and confidence judgments and found that the z-slopes from the two procedures were similar in 15 out of 16 different experiments from six different published studies. Malmberg and Xu (2006) also found that RK and confidence ROCs were indistinguishable. Overall, direct comparisons of RK and ROC results indicate that, in a vast majority of cases, sensitivity (z-intercept) and asymmetry (z-slope) are similar for recognition confidence and RK judgments and, thus, generally support the predictions of the UVSD and 2DSD models. The convergence of RK and confidence ROCs is also consistent with the STREAK model, but because it predicts that the remember point can have virtually any relationship to the confidence ROC, this convergence is not particularly useful for evaluating STREAK.

Although the UVSD, 2DSD, and STREAK models can account for the convergence of RK and recognition ROCs, all but the STREAK model are challenged by another common RK finding. Specifically, RK and confidence ratings produce very similar ROCs when they are directly compared within experiments, but in many other pure-RK experiments the z-slopes are much higher than would be expected from the item ROC literature. For example, Rotello et al. (2004) reviewed 373 published RK conditions and found that the average RK slope was close to 1.0, whereas item recognition slopes have an average around .80 (also see Dunn (2004) for a similar analysis), and in many cases the RK z-slopes were well above 1.0, something almost never seen in item recognition studies. Thus, the RK results are not always consistent with those from recognition ROC studies. Although the materials and test procedures may differ across the RK and ROC studies, thus complicating the comparison of the z-slopes, it is difficult to attribute the observed differences to this factor alone (see Wixted and Stretch, 2004).

To account for high RK z-slopes, Rotello et al. (2004) proposed the STREAK model, which can produce different slopes for confidence and RK studies, giving it an important advantage over the other signal detection models. However, a number of alternative measurement-artifact accounts have also been put forward to account for these results. For example, the RK z-slope would be artificially increased if subjects' criterion between remember and know responses varies over trials (Wixted and Stretch, 2004). Examining the z-slopes of the aggregate data (e.g., Rotello et al., 2004) rather than examining the subject-level z-slopes can also artificially increase the RK z-slope (Malmburg and Xu, 2006). Finally, Parks (2007) suggested that the remember responses might fall below the ROC if subjects adopt a strict definition of remembering such that only some aspects of the study event are treated as adequate to support a remember response. However, as of yet, none of these hypotheses have been extensively tested, and the reason for the high z-slopes remains somewhat of a mystery.

Other data that present some important challenges for the signal detection models are results from exclusion paradigms. In exclusion tests, subjects must reject or 'exclude' lures that are related in some way to the studied items or pairs. For example, on an associative test, subjects must reject rearranged pairs (e.g., 'magnet' – 'sheep,' after studying 'magnet' – 'phone' and 'corn' – 'sheep'); in conjunction tests they must reject compound words composed of previously studied words (e.g., 'blackbird,' after studying 'blackboard' and 'jailbird'); and in exclusion source tests, subjects must reject items from one source and accept only items from another source (e.g., accept only heard items as 'old' after studying both an auditory and a visual list). If unstudied items or pairs are included in the test list, then it is possible to plot the proportion of incorrectly accepted lures against the proportion of incorrectly accepted unstudied items or pairs, and this produces what we refer to as an 'exclusion ROC.' Like standard item ROCs, exclusion ROCs are curved downward, but they quickly approach the chance diagonal and in some cases pass below it. **Figure 8** presents representative exclusion ROCs from studies of source memory (Yonelinas, 1999a), word-pair recognition (Kelley and Wixted, 2001; Healy et al., 2005), and word-conjunction recognition (Lampinen et al., 2004). Each of the exclusion ROCs indicates that when subjects adopt a strict criterion they accept more lure items than new items (i.e., the ROC is above the chance diagonal), but as their criterion becomes more lax they are equally or more likely to accept a new item than a related lure item (i.e., the ROC approaches or goes below the chance diagonal). Curved, negative-going exclusion ROCs have been observed in several relational recognition experiments (Yonelinas, 1994; Kelley and Wixted, 2001; Lampinen et al., 2004; Healy et al., 2005), and the pattern appears fairly robust. Exclusion ROCs are linear in z-space, similar to item recognition, but their slopes range from .4 to .6 and, thus, appear to be considerably lower than those typically seen in item recognition tests.

The EVSD model cannot produce ROCs that cross the chance diagonal and, thus, fails once again, but the other signal detection models can account for the exclusion data. However, they do so by adopting rather questionable parameter values. For example, the UVSD model can often fit exclusion data well. However, in order to fit the conjunction data (Lampinen et al., 2004) in **Figure 8**, for example, the model parameters indicate that the study phase led to an average decrease in memory strength for the related lures ($d' = -1.20$), as well as a two- to threefold increase in the variance of the lures relative to the new items ($V_O = 2.71$). The fits of the UVSD model to the other exclusion ROCs are just as surprising. In the associative test (Kelley and Wixted, 2001), the model suggests that the study phase had virtually no effect on the average memory strength of the rearranged items (i.e., $d' = .096$), yet it almost doubled the variance of those items relative to the new pair distribution (i.e., $V_O = 1.83$), and a similar pattern was seen in the exclusion source test (i.e., $d' = 0.16$, $V_O = 1.95$; Yonelinas, 1994). These parameters indicate that the study phase increased the

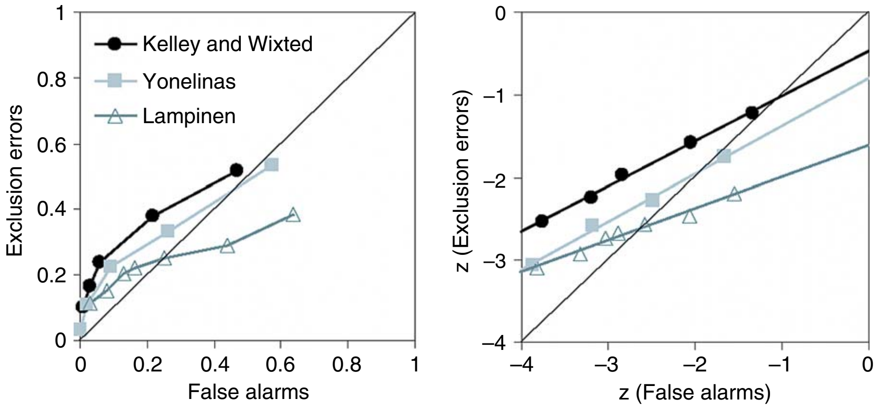


**Figure 8** Exclusion ROCs (left), which plot the probability of incorrectly accepting a related lure against the probability of accepting a new item, for (1) word-pair recognition (strong item condition from Experiment 1 in Kelley R and Wixted JT (2001) On the nature of associative information in recognition memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 701–722); (2) source recognition (short list condition from Experiment 1 in Yonelinas AP (1994) Receiver-operating characteristics in recognition memory: Evidence for a dual-process model. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 1341–1354); and (3) conjunction recognition (the multiple presentation condition from Experiment 2 in Lampinen JM, Odegard TN, and Neuschatz JS (2004) Robust recollection rejection in the memory conjunction paradigm. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 332–342). The exclusion ROCs are concave and negative-going in probability space. The right panel depicts the same data in z-space and shows that the zROCs are linear.

strength of about half of the exclusion items and decreased the strength of the other half, yet did not alter the Gaussian shape of the distributions. These paradoxical conclusions suggest that the model is simply not appropriate for exclusion ROCs.

## 2.23.5 Hybrid Models

Various models have been proposed that combine the assumptions of signal detection theory and threshold theory. These models assume that a signal detection process is supplemented by either a recollection process or a probabilistic attention process. Generally, these models differ from the previous models in that they assume that both types of processes (a threshold process and a signal-detection process) contribute to recognition memory. Therefore, the following models all assume that some component of recognition memory is deterministic and always successful in some sense (like the signal detection models), whereas another component is probabilistic and therefore subject to failure (like the threshold models).

### 2.23.5.1 Dual-Process Signal Detection Model

The dual-process signal detection model (DPSD) (e.g., Yonelinas, 1994, 2001) integrates signal detection theory and threshold theory within a dual-process framework of recognition memory (e.g., Atkinson and Juola, 1974, Mandler, 1980; Jacoby, 1991). The DPSD model was the first hybrid model in the recognition memory literature, and thus it has been applied to the widest range of recognition paradigms so far. The model assumes that recognition memory judgments are based on a recollection process whereby qualitative information about the study event is retrieved (e.g., where or when an item was studied), or if recollection fails, recognition is based on a familiarity assessment process like that underlying the equal-variance signal detection model (see **Figure 9**). Thus, recollection and familiarity are assumed to be qualitatively different processes that yield different types of mnemonic evidence. All items are assumed to evoke a familiarity signal, but only some items will be recollected. As such, recollection is indexed as the probability that subjects recollect some aspect of the study event ($R_T$), whereas familiarity is indexed as the increase in familiarity related to the study phase ($d'$). It is assumed that subjects can recollect different types or amounts of information about a study event, but that recollection will sometimes fail and no qualitative information will be retrieved. Because it is subject to failure, recollection is described as a threshold process. Note that recollection is assumed to have a distribution of strength, but the model does not specify what kind of distribution it

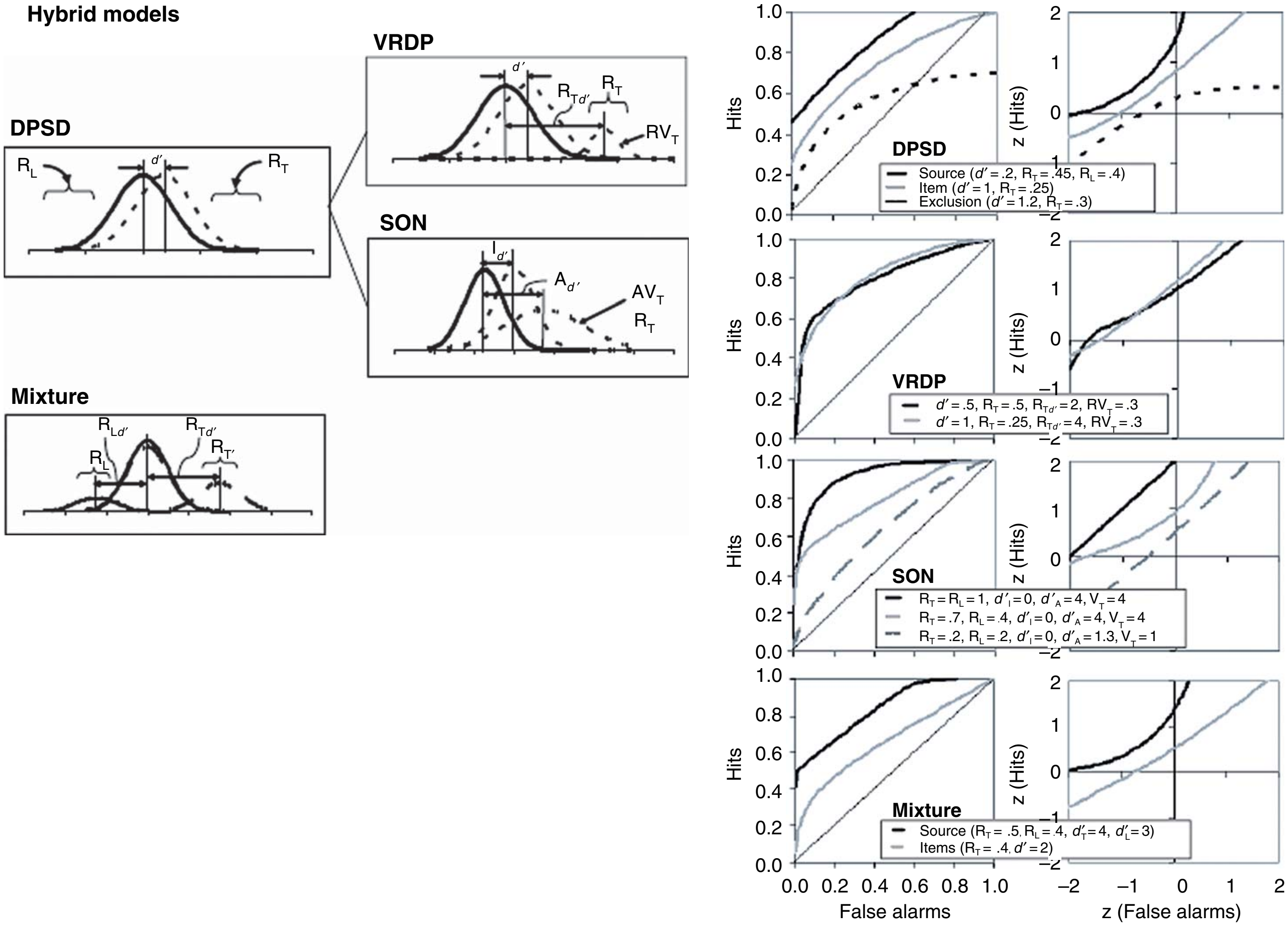


**Figure 9** Strength distributions and predicted ROCs and zROCs for the hybrid memory models, including the dual-process signal detection (DPSD), variable-recollection dual-process (VRDP), some-or-none (SON), and mixture models.

is and thus measures recollection in the probability of success (there is an arrow labeled $R_T$ pointing to an empty space in the depiction of DPSD in **Figure 9** because of this; i.e., the model doesn't specify what the recollection distribution looks like). Also, because recollection produces qualitative evidence of prior occurrence, it is assumed to lead to a relatively high-confidence recognition response. Familiarity-based responses are expected to be spread across the entire range of response confidence.

Unlike the signal detection models, which predict only curvilinear ROCs and linear zROCs, the DPSD model predicts different ROC/zROC shapes for different types of recognition depending on the relative contribution of recollection and familiarity. In tests of item recognition, the model predicts curved asymmetrical ROCs (see **Figure 9**). The familiarity component of the model leads to symmetrical curved ROCs like that of the signal detection model, but recollection increases the proportion of high-confidence recognition responses to old items and thus pushes the ROC up on the left side, making it asymmetrical. Although the predicted item ROCs are approximately linear in z-space, the threshold recollection process leads the zROCs to be slightly U shaped (Glanzer et al., 1999; Yonelinas, 1999b). However, the predicted curve for item recognition is typically so slight that it is not detectable (Yonelinas, 1999b). Overall, the two processes have different effects on ROC shape, which allows the model to predict experimental dissociations between sensitivity and symmetry. In general, both processes can increase overall performance, but recollection makes the ROC asymmetrical, whereas familiarity makes the ROC curved downward.

Because the shape of the ROC is determined by recollection and familiarity, and the functional nature of these processes has been reasonably well characterized (see Yonelinas, 2002), the DPSD model can be used to generate predictions about how different experimental variables will influence ROC shape. For example, because manipulations like deep versus shallow levels of processing and full versus divided attention increase recollection much more than familiarity, the model predicts that these manipulations should lead the z-slope of the ROCs to decrease as performance goes up. In contrast, manipulations that have comparable effects on both processes, such as study duration, should lead the z-slopes to be roughly constant as performance goes up. Additionally, because recollection is expected to be particularly disrupted in patient groups such as medial temporal lobe amnesics, the degree of asymmetry should differ for amnesics and controls, with much more symmetrical ROCs for amnesics than for controls. Further, if the hippocampus is critical for recollection, but not for familiarity (e.g., Eichenbaum et al., 1994; Aggleton and Brown, 1999; Yonelinas, 2002), an ROC analysis should indicate that individuals with selective hippocampal damage have a deficit in recollection, but not familiarity.

Because the model assumes that recollection and familiarity serve as two different bases for recognition responses, it allows recollection and familiarity to act in opposition to one another, as in exclusion tests (e.g., Jacoby, 1991), for which it predicts curved and negative-going ROCs (see **Figure 9**). For example, when subjects are instructed to accept items from one source as 'old' but to reject items from a different source as 'new,' familiarity for the to-be-excluded items will lead to a yes response and downward-curved ROCs. However, recollection, which is used to reject the excluded-source items, pushes the ROC downward. This happens because recollection decreases the number of exclusion errors (which are plotted on the y-axis instead of the hit rate in exclusion ROCs) by leading to many high-confidence rejections (i.e., many 'sure new' responses). Thus, while familiarity in the absence of recollection will result in a typical-looking ROC by leading to exclusion errors across the confidence range, recollection limits the number of errors that will be made, thereby forcing the right side of the ROC down. The resulting ROC is curved downward and crosses the negative diagonal as the familiarity response criterion is relaxed (Yonelinas, 1994; Yonelinas et al., 1995). In z-space the exclusion ROC is generally linear and will have a z-slope of less than 1.0, but with large recollection values the zROC starts to exhibit an inverted-U shape.

The DPSD model has also been applied to tests of relational recognition (see **Figure 9**; e.g., Yonelinas, 1997, 1999a). For relational recognition, an additional recollection parameter ($R_L$) is required to account for the probability of recollecting a lure item as a lure. For example, in source memory tests, the probability of recollecting items from the two different sources can be quite different; thus a separate recollection parameter is required for each source. One of the sources is arbitrarily referred to as the target source and the other as the lure source. Similarly, in associative memory tests subjects must discriminate between studied pairs (targets) and rearranged pairs (lures). Like the predicted item ROCs, familiarity leads the relational ROCs to be curved, and recollection tends to make them more linear. However, because familiarity is usually expected to play a lesser role in relational than in item recognition, and because recollection contributes to the recognition of lures as well as targets, the ROCs should be more noticeably linear, and the zROCs more U-shaped.

It is sometimes assumed that subjects are aware of recollection and familiarity, and that they can report on their occurrence (e.g., Yonelinas and Jacoby, 1995; Yonelinas et al., 1996). Remember responses are assumed to provide an indirect index of recollection and thus should be associated with high-confidence recognition responses, whereas know reports provide an index of familiarity in the absence of recollection, and thus can be associated with high and low levels of confidence. If this is the case, then the RK responses should fall along the same function as the confidence ROC. That is, the remember ROC point should fall to the left of the remember + know responses, and both points should fall along the confidence ROC. The remember point should be close to the highest confidence ROC point, but will be shifted slightly to the right if there are also high-confidence responses based on familiarity. Because the RK and ROC points should fall along the same function, the z-slope of the RK and ROC results should be comparable.

Finally, the DPSD model has also been applied to neural monitoring methods, such as ERP and fMRI methods, as well as studies of medial temporal lobe amnesics. At the most basic level, the model predicts that there should be two distinct neural signals associated with recognition performance, one related to measures of recollection and another related to measures of familiarity. In line with recent neuroanatomical models (e.g., Aggleton and Brown, 1999), the model also assumes that the hippocampus preferentially supports recollection, whereas the surrounding neocortex, such as the perirhinal cortex, supports familiarity-based recognition. Medial temporal lobe amnesics, who often have more damage to the hippocampus than to surrounding neocortex, are therefore expected to have greater recollection than familiarity deficits. The recollection deficits are expected to lead to more symmetrical ROCs than those typically seen for healthy control subjects. Finally, if the damage is restricted to the hippocampus, the model predicts that familiarity should be preserved and only recollection will be impaired.

### 2.23.5.2 Variable-Recollection Dual-Process Model

The variable-recollection dual-process model (VRDP) is a modification of the DPSD model in which recollection is assumed to be a thresholded signal detection process (see **Figure 9**; Sherman et al., 2003; for related modifications of the DPSD model also see Macho, 2004; Healy et al., 2005). As in the DPSD model, familiarity is treated as an equal-variance signal detection process ($d'$), and recollection is a threshold process in the sense that only some of the studied items will be recollected ($R_T$). The critical modification is the explicit modeling of recollective strength. Specifically, recollected items produce a Gaussian distribution with a mean level of strength ($Rd'$) and some variability around that mean ($RV_T$). Thus, items will be recognized if they are recollected and their recollection strength exceeds the response criterion, or if they are not recollected, but the familiarity strength exceeds the response criterion. Conceptually, the VRDP and the DPSD model are nearly identical. However, by allowing the variance of recollection to vary, the VRDP model allows for the possibility that recollection-based responses could receive lower confidence ratings than familiarity-based responses, contrary to the assumptions of the DPSD model. Psychologically, this would imply that recollection of contextual details sometimes produces less reliable evidence of prior occurrence than a feeling of familiarity. However, the VRDP model retains the assumption that recollection is the dominant process and, when successful, will dictate the final recognition response.

In general, the VRDP model makes the same predictions as the DPSD model. For example, the predicted item recognition ROCs are identical to the DPSD model, because if the recollection strength distribution falls above the high-confidence response criterion, then all the recollection responses lead to high-confidence responses, and the model collapses into the original DPSD model. However, if some portion of the recollection distribution falls below the high-confidence response criterion, then some of the recollected items can receive lower confidence responses. Thus, the model can produce ROCs that are slightly more curved than the DPSD model. In z-space, the ROCs are slightly U shaped across most of the range, but they can bend downward as the response criterion becomes strict (see **Figure 9**). The model is relatively new and has not been applied to many paradigms yet, and thus its predictions have not yet been specified. However, our own calculations suggest that the model is flexible enough to predict a wide array of ROC results. Nonetheless, it will clearly be important for more theoretical and empirical work to be done to further flesh out the model's predictions.

### 2.23.5.3 Some-or-None Model

The some-or-none model (SON) is another modification of the DPSD model proposed by Kelley and Wixted (2001) to account for associative recognition (see **Figure 9**). The model assumes that memory judgments are based on assessments of associative memory strength and item memory strength, both of which are signal detection processes. Kelley and Wixted use the terms item memory and associative memory, but to be consistent with the other models we use the terms familiarity and recollection, respectively. Although both familiarity and recollection are signal detection processes, the retrieval of associative information is also probabilistic, meaning that only some proportion of the pairs will be recollected, and thus recollection is also a threshold process. Because the model assumes that recollection can fail, but that it varies in strength when successful, recollection is referred to as some-or-none. The item and associative distributions each require a strength parameter ($d'_I$ and $d'_A$, for item and associative strength, respectively). The variance of the old item strength distribution is assumed to be 1.0 (equal to that of the new item distribution), whereas the variance of the old associative strength distribution is free to vary ($V_A$). The strength distributions for item and associative information are illustrated in **Figure 9**. The probability of retrieving associative information about a studied pair ($R_T$) is assumed to be greater than or equal to the probability of retrieving information about a rearranged pair ($R_L$).

Importantly, and in contrast to the other dual-process models, the SON model assumes that item and associative strength are combined and equally weighted when making associative recognition judgments. In fact, this is really the only difference between the SON and VRDP models. That is, although both models allow recollective strengths to fall below familiarity strengths, the VRDP model still assumes that recognition decisions are dominated by recollection such that successful recollection will dictate the final response. This is not the case for the SON model. In the SON model, an intact pair will be recognized if associative retrieval is successful ($R_T$) and the sum of the associative and individual item strengths exceeds the response criterion; or if associative retrieval fails but the item strength still exceeds the response criterion. In contrast, a rearranged pair will be correctly rejected if it is recollected as rearranged ($R_L$), and the item strength minus the associative strength is lower than the response criterion; or if recollection fails and the item strength is lower than the response criterion. Importantly, the resulting strength distributions for intact and rearranged pairs (which are not illustrated) form mixtures of two Gaussian distributions (item strength alone, and item plus or minus associative strength when recollection is successful); because the mixed distributions are usually not Gaussian, the model can produce nonlinear zROCs.

Kelley and Wixted (2001) argued that the variance of the associative distribution must be much greater than that of the item strength distribution in order to produce appropriate ROC results, but subsequent work with the model suggested that this was not a necessary assumption and indicated that the model could fit associative recognition without making this restrictive assumption (Macho, 2004; Healy et al., 2005). Our calculations support the latter claim.

In exploring the effects of the different parameter values on the predicted ROCs, we found that the model was capable of producing a wide variety of curved and linear ROCs at various different levels of performance (see **Figure 9**). Like threshold theory, the $R_T$ and $R_L$ parameters determine the apparent intercepts of the ROCs, and thus they control the degree of ROC asymmetry. That is, $R_T$ determines the left y-intercept, and $R_L$ determines the upper x-intercept. We refer to the intercepts as 'apparent' because the Gaussian distributions lead the ROCs to curve prior to actually intersecting the axes. In general, as associative strength increases, the predicted ROCs become more linear. This occurs because the farther apart the distributions are, the less Gaussian the mixed (item + associative) distributions will be. In contrast, as the variance of the associative strength decreases (i.e., approaches the variance of the item distribution), the ROCs become more curved. In z-space, the model predicts ROCs that have a slope less than 1.0 when $R_T$ / $R_L$. The zROCs are approximately linear but become nonlinear as associative strength increases, generally exhibiting a U shape, but bending slightly downward at extreme criterion values. Importantly, when $R_T$ and $R_L$ approach 1.0, the predicted ROC will become symmetrical, and as long as the associative strength is not too high, the zROC will be linear. That is, as recollection approaches 1.00, the mixed distribution upon which judgments are based becomes Gaussian.

### 2.23.5.4 Mixture Model

The mixture model is another extension of signal detection theory that has been proposed to account for item and source recognition (see **Figure 9**; DeCarlo, 2002, 2003; Hilford et al., 2002). In tests of item recognition, it is assumed that memory judgments are based on the assessment of item strength in a manner consistent with the signal detection model (e.g., it assumes equal-variance Gaussian memory strength distributions). However, an attentional process is also included such that only some proportion of the studied items will increase in memory strength (i.e., the attended items). Decarlo uses the term $\lambda$ (lambda) to designate the probability that a target item is attended, but to be consistent with the other models we use the term $R_T$. In this way, the new items form a normal strength distribution, but the old items form a mixture (which is not illustrated) of two equal-variance normal strength distributions (which are illustrated), one overlapping with the new item distribution and the other shifted to the right by some constant ($d'$). The one overlapping with the new items are those items that were part of the study phase but that were unattended; those that increase in strength are the items that were attended. Thus, the primary difference between this model and the previous hybrids is that it treats recognition as a simple evaluation of strength or familiarity (i.e., as a single process), and assumes that the threshold component (attention) is involved only during the study phase.

One motivating factor behind the development of this model was to avoid a perceived problem with the UVSD model, which is that the model predicts ROCs that cross the chance diagonal. As discussed earlier, the increased variance of old items relative to new items means that the study phase may have led some items to decrease, rather than increase, in memory strength. That is, it places no restriction on how the old items change in memory strength in order to achieve that greater variance. The mixture model avoids this problem by only allowing the memory strength to be increased or to remain unaffected by the study event.

The same model is used in tests of source memory except that memory strength is assumed to reflect how strongly each item matches one of two sources (**Figure 9**). That is, studying items in one source (i.e., the arbitrarily chosen 'target' source) increases source strength and shifts the items to the right ($R_T$), whereas studying items in the other source (i.e., the lure source) decreases source strength and shifts the items to the left ($R_L$). As in the item recognition model, only items that are attended at study will be associated with a change in memory strength; thus the source model requires two strength parameters and two attention parameters. Both the item and source models can be extended by adding additional parameters to allow for different levels of attention, but the effects of such modifications have not been explored.

In tests of item recognition, the model predicts asymmetrical curved ROCs that are approximately linear in z-space, with slopes less than 1.0 (see **Figure 9**). The equal-variance Gaussian distributions underlying the model lead it to generate curved symmetrical ROCs, but because only some of the old items increase in strength, this effectively increases the variance of the old item distribution relative to the new item distribution, leading the ROC to be asymmetrical and to have a z-slope of less than 1. Although the ROCs are approximately linear in z-space, the predicted zROCs can have a slight U shape and can even exhibit a subtle downward trend at the extreme criterion values. The nonlinearity arises because of the probabilistic attention process that effectively divides the old items into two distributions (i.e., the attended and unattended items). When attention is very low or high, the mixed distribution (i.e., the mixture of the attended and unattended items, which is not illustrated) is effectively normal, because nearly all items fail to increase in strength (low attention), or nearly all items do increase (high attention). At intermediate values of attention, though, the two portions of the mixture distribution will be more removed from one another, depending on the average strength of the attended items, thereby leading the overall old item (or mixed) distribution to be non-Gaussian.

In tests of source memory, the predicted ROCs are similar to those predicted in item recognition, but because there are two, rather than one, probabilistic attention parameters influencing performance, the ROCs tend to be flatter in probability space and more noticeably U shaped in z-space (see **Figure 9**).

To determine how the model's parameters influence the shape of the item ROC, we explored different parameter values and found that the degree of predicted nonlinearity in the zROC is not greatly affected by changes in attention when strength is held constant (and relatively low), except at the extremes. However, when attention is midrange, increases in strength result in more pronounced nonlinearity because the two portions of the mixture distribution move farther apart, making the resulting mixed distribution less normal in shape. In item recognition, increases in strength also produce more asymmetrical ROCs (i.e., the z-slope decreases). However, the attention parameter has a nonmonotonic relationship to z-slope. That is, intermediate levels of attention lead the old items to be distributed between the attended and unattended distributions, which increases old item variance and leads to z-slopes of less than 1.0. However, as attention either decreases toward 0 or increases toward 1.0, all the old items are forced into the lower portion (unattended) or the upper portion (attended) of the old item distribution, respectively, producing a symmetrical ROC (z-slope = 1.0).

Because the model assumes that one of the memory processes underlying the ROCs is an attentional encoding process, several general predictions can be made about the effects of different experimental manipulations on ROCs. For example, manipulations expected to influence attention at encoding (e.g., study duration, levels of processing, dividing attention, and word frequency – see Decarlo (2002, 2003) for a discussion of these variables) will not necessarily affect the degree of z-linearity, unless they result in large differences in attention and strength. However, increasing attention at study can lead to a decrease in slope (i.e., an increase of the variance of the old item distribution), then as attention increases further and goes toward 1.0 the pattern should reverse and could lead to an increase in slope (i.e., the variability of the mixed old item distribution decreases back toward that of the new item distribution). In contrast, experimental manipulations that do not affect attention during encoding (e.g., study-test delay or manipulations at the time of test) should only affect the ROCs by changing the strength parameter. Thus, these manipulations should lead the zROCs to become more nonlinear as strength increases (assuming a constant midrange attention parameter), and in the case of item recognition, the z-slope should decrease.

### 2.23.5.5 Evaluation

The hybrid models can account for item recognition as well as the relational recognition ROC data. The existing data do not clearly differentiate between the different hybrid models, although there is some suggestion that the models that incorporate recollection and familiarity process may fare best.

Because the hybrid models include a Gaussian signal detection process they can produce inverted U-shaped ROCs typically seen in item recognition and sometimes seen in relational recognition. And because they all incorporate a threshold process (recollection or attention), they can produce U-shaped zROCs found in relational recognition. Thus, the models are able to account for the shapes of the ROCs seen in both item and relational recognition studies, in both probability and z-space. Indeed, because the relative contributions of recollection and familiarity are expected to differ for the two types of tests, the hybrid models that incorporate those processes predict the different ROC shapes found in the two types of tests. The models also deal well with the variations in asymmetry found in item ROCs. For example, for the DPSD model, increases in recollection should be accompanied by increases in sensitivity and decreases in z-slope – a pattern found for manipulations such as levels of processing and divided attention (e.g., Yonelinas, 2001; Yonelinas et al., 1996). When both recollection and familiarity increase, overall sensitivity should increase too, but the degree of asymmetry should remain constant – a pattern seen with manipulations like repetition and study duration (see Glanzer et al., 1999, for a review). Because the SON and VRDP models are extensions of the DPSD model, it is likely that they too can account for these results. The mixture model can also account for these results, because it can accommodate changes in strength as well as changes in asymmetry.

The hybrid models also accurately predict the convergence found between RK and confidence ROCs when they are directly compared under the same conditions. For example, for the DPSD model, recollection is expected to lead to high-confidence responses, so the RK data should fall on the same function as the ROCs. A similar account can be provided by the VRDP model. Neither the SON nor the mixture model has been directly applied to RK results yet, but they might account for this convergence by assuming that remember responses simply reflect the strongest items.

The DPSD, VRDP, and SON models can all account for the curved and negative-going exclusion ROCs, as described earlier. Because each of these models includes separate recollection and familiarity processes that can work in opposition to each other, the familiarity component of the model produces the curvilinear shape of the ROC, and the recollection component pushes the ROC toward the chance line as the criterion becomes more lax. The mixture model has not yet been applied to exclusion data, but our simulations suggest that it is not able to account for the exclusion ROCs in its current form. That is, the model predicts that the probability of accepting a new item should always be greater than the probability of accepting a lure item in an exclusion test, and therefore the entire exclusion ROC falls below the chance line, contradicting observed data.

However, none of these hybrid models can easily account for the high RK z-slopes that are sometimes reported (e.g., Rotello et al., 2004). The DPSD model predicts that the remember point should fall on the confidence ROC function, although it may be possible that the model could account for these high slopes by incorporating a false recollection parameter (Rotello et al., 2004). If successful, then a similar modification might allow the other models to account for these data as well, but this possibility remains to be explored. If the measurement artifact accounts of this finding can be ruled out then, these results will pose a serious problem for these models, and would suggest an approach like that underlying the STREAK model might be useful.

The DPSD and VRDP models both predict that distinct neural correlates of recollection and familiarity should be found and, therefore, match the neural findings from ERP and fMRI methods to date (Eichenbaum et al., 2007). That is, ERP studies have identified two dissociable correlates of accurate recognition decisions (see **Figure 10** for an example; for reviews see Friedman and Johnson, 2000; Mecklinger, 2000; Rugg and Yonelinas, 2003; Curran et al., 2006). The first is a frontocentral negativity that onsets about 400 ms after stimulus onset, and the second is a late positive component largest over the left parietal region that arises approximately 500 ms after stimulus onset. The slower component has been linked to recollection in the sense that it is associated with (1) remember compared to know responses, (2) accurate compared to inaccurate source recognition responses, (3) accurate compared to inaccurate judgments in plurality-reversed recognition, and (4) high-confidence old responses in item recognition. In contrast, the earlier effect has been linked with familiarity in the sense that it is associated with accurate recognition, but does not distinguish between (1) remembering and knowing, (2) accurate compared to inaccurate source

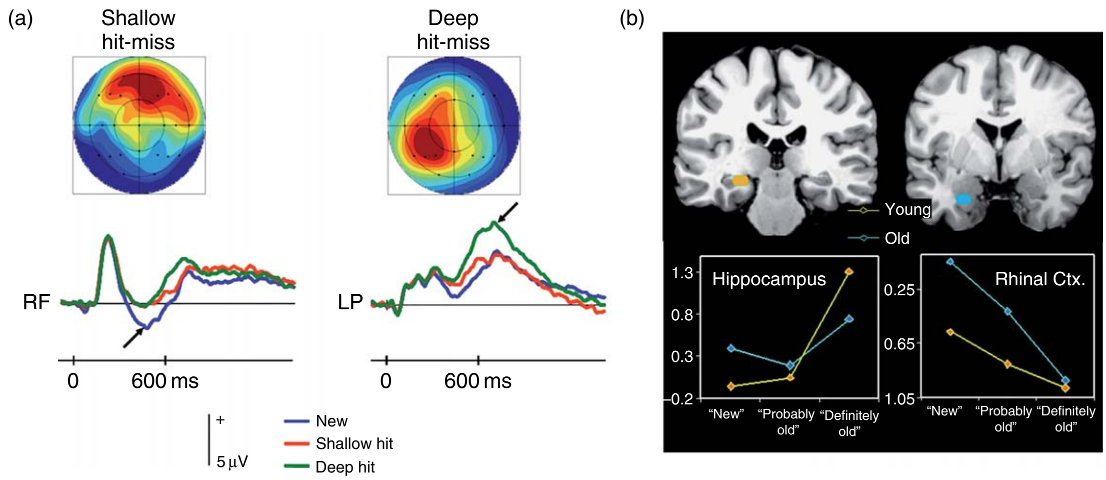


**Figure 10** (a) ERPs illustrating an early N400 negativity (left panel) associated with familiarity and a late positive component (right panel) related to recollection. From Rugg MD, Allan K, and Birch CS (2000). Electrophysiological evidence for the modulation of retrieval orientation by depth of study processing. *J. Cogn. Neurosci.* 12(4): 664–678. In this study, the familiarity effect was evident for deeply and shallowly encoded items, whereas the recollection effect was most pronounced for the deeply encoded items. (b) Neural activity related to recognition confidence. From Daselaar SM, Fleck MS, Dobbins IG, Madden DJ, and Cabeza R (2006) Effects of healthy aging on hippocampal and rhinal memory functions: An event-related fMRI study. *Cereb. Cortex* 16(12):1771–1782. Hippocampal activity was associated with high-confidence old responses, but did not change across lower levels of confidence. In contrast, rhinal activity decreased monotonically as recognition confidence increased.

recognition, (3) accurate compared to inaccurate plurality recognition judgments, or (4) high versus low recognition confidence.

fMRI studies have revealed similar dissociations (for a review see Eichenbaum et al., 2007). For example, studies using RK, relational recognition, and ROC confidence methods have indicated that recollection is consistently associated with hippocampal activation and only rarely with perirhinal activation. In contrast, familiarity is consistently associated with perirhinal activation and only rarely related to changes in hippocampal activation (see **Figure 10** for an example).

The ERP and fMRI results present challenges to the mixture and SON models. First, the mixture model assumes that recognition decisions are based solely on an assessment of familiarity strength and therefore does not deal well with the finding of dissociations between neural signals during test. Because the SON model includes two components, it can deal with these dissociations, but it assumes that recognition responses are based on the summed and equally weighted familiarity and recollection information, such that items high in memory strength may reflect any combination of familiarity and recollective strengths. Thus, the relationship seen between measures of recollection, distinct neural signals, and high-confidence recognition responses is not readily explained by the model. Specifically, because the information from the two processes is combined to make a decision, it is not clear why the neural correlates of these processes would have such specific relationships to recognition confidence.

Results from studies of medial temporal lobe amnesia also seem to be in accord with the predictions of the DPSD and VRDP models. First, studies using RK, ROC, and confidence methods of measuring recollection and familiarity have shown that patients with damage to the hippocampus and surrounding cortex have deficits in recollection and a smaller, but consistent, deficit in familiarity (e.g., Cipolotti et al., 2006; Yonelinas et al., 1998, 2002). Second, patients with damage that is restricted to the hippocampus have relatively selective recollection deficits (Aggleton et al., 2005; Yonelinas et al., 2002; but see Manns et al., 2003; Yonelinas et al., 2004, for discussion). These differences have been demonstrated experimentally in rats – damage restricted to the hippocampus produced a selective recollection deficit (Fortin et al., 2004). And in accord with the DPSD model's third prediction, amnesics' ROCs are typically more symmetrical than those of controls (e.g., Yonelinas et al., 1998, 2002; Aggleton et al., 2005; Cipolotti et al., 2006; Wais et al., 2006), and this is true even when performance is equated between the groups (e.g., Yonelinas et al., 1998). The SON model may also be able to account for these data because it includes both recollection and familiarity, but it is less clear how the mixture model would deal with these findings, because it assumes that recognition is based on a single strength-assessment process.

Overall, the DPSD, VRDP, and SON models deal with the neural findings the most easily. The DPSD has been most extensively applied to these data and specifically predicts the dissociations of neural signals, the relationship between hippocampal activity and recollection measures, as well as the differences in ROC asymmetry found in amnesics and controls. The VRDP model, as an extension of the DPSD model, can also account for these data. The SON model has not been applied to neural data, but given its similarity to the DPSD model, should be capable of handling these patterns, though whether the parameters will provide psychologically reasonable accounts is still unknown. The mixture model is the only one to face immediate challenges by the neural data. Specifically, because it assumes a single process underlying recognition performance at test, it cannot easily account for the dissociations found in the ERP and fMRI literature or for the patterns of differential deficits in amnesia.

## 2.23.6 Alternative Theoretical Frameworks

The models just evaluated represent a broad range of different theoretical approaches to recognition, but the list is hardly exhaustive. The current analysis, however, is relevant to many more current models, because many of the predictions reviewed here parallel those of models that we did evaluate. In this section we discuss the implications of the current findings to a number of these alternatives.

A number of models have adopted the assumption underlying threshold theory, such as multinomial models (for a review see Batchelder and Riefer, 1990) that are often applied to source memory tests (e.g., Bayen and Murnane, 1996; Bayen et al., 1996; Belleza, 2003). Given the poor performance of the threshold models in item recognition, it follows that the multinomial models also fail to provide an acceptable account of item recognition. The story in source recognition is a little more complicated, where it appears as though the threshold notion does work reasonably well for some source memory studies, in the sense that the ROCs can be close to linear. However, even if restricted solely to source decisions, multinomial models still seem inadequate because of the finding that source ROCs can often be curved. This indicates that the threshold notion is not entirely correct for relational recognition either. Although there may be ways of modifying the multinomial models to bring them more in line with the curved ROCs (e.g., adding more thresholds or considering different response strategies, Malmberg, 2002), it is clear that without modification those models do not provide a very good account of item or relational recognition performance.

The problems that arise for signal detection theory also have far-reaching implications, because so many current theoretical accounts of recognition memory have been built upon this framework. For example, the $d'$ statistic used to measure memory sensitivity depends critically on the validity of the Gaussian and equal-variance assumptions. Although the Gaussian assumption appears to be approximately right in tests of item recognition, it is certainly not appropriate in relational recognition tests, and the equal-variance assumption is violated in nearly every item recognition experiment (i.e., ROC slopes are less than 1.0). However, even if one opts to use $d'$ despite these problems, it is not a sufficient measure by itself – a measure of the second memory component (i.e., the variance ratio, recollection, or attention) is necessary to accurately describe performance as well. The observed ROCs are also problematic for various other models that are based on signal detection theory. For example, global memory models such as TODAM and SAM generally base recognition judgments on an assessment of a Gaussian memory strength signal, and as such they are not consistent with the U-shaped zROCs observed in relational recognition tasks. Moreover, the dissociation of sensitivity and asymmetry observed in item and relational recognition studies also presents problems for these models (for earlier discussions see Ratcliff et al., 1992; Clark and Gronlund, 1996). For example, models like SAM and Minerva 2 (Hintzman, 1984) predict that the ROCs should become more asymmetrical as performance increases, which is not consistent with what is seen with manipulations like study duration, which increase performance but not the slope. In contrast, TODAM predicts that the slope should remain relatively constant, which is not consistent with what is observed with manipulations like levels of processing, which affect both performance levels and slope. Note, however, that some of these models include recall mechanisms that might be used to supplement standard recognition in such a way as to produce non-Gaussian memory strength distributions, though it is not yet known whether such modifications would produce the observed pattern of ROC results. The SAC model of Reder et al. (2000) is another computational model (it starts at the level of representations), but one that incorporates familiarity and recollection processes. The model assumes that familiarity reflects the assessment of the activation of word nodes, whereas recollection reflects the assessment of activation of nodes that represent specific events. Both processes rely on assessments of activation in a manner consistent with signal-detection theory, so the model does not provide an account for the U-shaped zROCs, but whether it can be modified to do so is not yet clear (for discussion see Diana et al., 2006).

One computational model that appears to be consistent with the dual-process models considered is the complementary learning systems model (e.g., McClelland et al., 1995; O'Reilly and Rudy, 2001; Norman and O'Reilly, 2003). The model is based on the assumption that the hippocampus supports recollection by developing minimum overlapping representations of prior episodes, whereas the surrounding cortex gradually tunes populations of cortical units to respond strongly to different stimuli in such a way that it can discriminate between familiar and new items. A review of the model goes beyond the scope of the current paper (for a detailed discussion see Norman and O'Reilly, 2003), but the results from preliminary simulations are promising, because they indicate that the model can account for the differential importance of hippocampal versus the surrounding neocortex in recollection and familiarity and successfully predicts behavioral properties of recollection that other computational models have not (Elfman et al., unpublished data). For example, the hippocampus produces a threshold output such that it can produce linear ROCs, whereas the cortex produces curvilinear ROCs. It is not yet clear whether the model is able to account for the full body of results that have been discussed; however, models such as this one are particularly promising, because they aim to incorporate the behavioral and neuroanatomical knowledge about recollection and familiarity within the same theoretical framework.

## 2.23.7 Conclusions

In this chapter, we have examined several quantitative models of recognition memory, highlighting their assumptions and predictions, and finally focusing on how well those predictions have been supported by the data. The evidence strongly disconfirms the pure threshold and signal detection models. Pure threshold models fail outright in nearly every recognition domain. Although there are some sets of relational recognition data that threshold theories can adequately describe, they still fail to explain the wider range of findings of both linear and curvilinear ROCs. Pure signal detection models fare better than the pure threshold models, but they too face a fairly overwhelming challenge. They are unable to deal with curvilinear zROCs and therefore cannot account for the relational recognition results, including source, associative, and plurality-reversed recognition. However, they may still be relevant in particular tasks – for instance the UVSD model accounts for item recognition very well, and STREAK can account for nearly any RK pattern found. In our view, though, a model aimed at describing recognition performance should be aimed at more than a single task, especially given that there are several models which do so already.

The examination of ROC data from a wide range of recognition memory paradigms also indicates that single-component models of recognition memory are inadequate, and that there are at least two functionally and anatomically distinct component/processes involved in recognition. To account for ROC results, current models have incorporated several different theoretical divisions such as the distinctions between recollection/familiarity, item/associative information, attention/familiarity, and strength/variance. Although there is support for all of these distinctions, in general, only the hybrid models assuming the contribution of signal detection and threshold processes were successful at accounting for the existing literature (e.g., recollection/familiarity; attention/familiarity).

Although the existing results argue strongly against pure threshold and pure signal detection models and strongly in favor of the hybrid models, the current review does not provide definitive evidence for the superiority of one hybrid model over the others. And importantly, models that produce non-Gaussian distributions by means other than including both signal detection and threshold processes have yet to be seriously explored. Our hope, however, is that in examining the theoretical background and core assumptions of the existing models we have come to more clearly see which classes offer the most promise in explaining the data, as well as the important empirical and theoretical questions that need to be answered. In so doing, we hope that the next phase of ROC research will focus on testing competing predictions of these various hybrid models and lead to a deeper understanding of recognition memory.

## References


Aggleton JP and Brown MW (1999) Episodic memory, amnesia, and the hippocampal-anterior thalamic axis. *Behav. Brain Sci.* 22: 425–444.

Aggleton JP, Vann SD, Denby C, et al. (2005) Sparing of the familiarity component of recognition memory in a patient with hippocampal pathology. *Neuropsychologia* 43(12): 1810–1823.

Arndt J and Reder LM (2002) Word frequency and receiver operating characteristic curves in recognition memory: Evidence for a dual-process interpretation. *J. Exp. Psychol. Learn. Mem. Cogn.* 28: 830–842.

Ashby FG (1992) Multidimensional models of categorization. In: Ashby FG (ed.) *Multidimensional Models of Perception and Cognition*, pp. 449–483. Hillsdale, NJ: Lawrence Erlbaum Associates.

Atkinson RC and Juola JF (1974) Search and decision processes in recognition memory. In: Krantz DH, Atkinson RC, Luce RD, and Suppes P (eds.) *Contemporary Developments in Mathematical Psychology, Vol. 1: Learning, Memory and Thinking*, pp. 242–293. San Francisco: Freeman.

Banks WP (1970) Signal detection theory and human memory. *Psychol. Bull.* 74: 81–99.

Banks WP (2000) Recognition and source memory as multivariate decision processes. *Psychol. Sci.* 11: 267–273.

Batchelder WH and Riefer DM (1990) Multinomial processing models of source monitoring. *Psychol. Rev.* 97: 548–564.

Bayen UJ and Murnane K (1996) Aging and the use of perceptual and temporal information in source memory tasks. *Psychol. Aging* 11(2): 293–303.

Bayen UJ, Murnane K, and Erdfelder E (1996) Source discrimination, item detection, and multinomial models of source monitoring. *J. Exp. Psychol. Learn. Mem. Cogn.* 22(1): 197–215.

Bellezza FS (2003) Evaluation of six multinomial models of conscious and unconscious processes with the recall-recognition paradigm. *J. Exp. Psychol. Learn. Mem. Cogn.* 29(5): 779–796.

Boring EG (1929) *A History of Experimental Psychology*. New York: The Century Co.

Buchner A, Erdfelder E, and Vaterrodt-Pluennecke B (1995) Toward unbiased measurement of conscious and unconscious memory processes within the process dissociation framework. *J. Exp. Psychol. Gen.* 124: 137–160.

Cipolotti L, Bird C, Good T, Macmanus D, Rudge P, and Shallice T (2006) Recollection and familiarity in dense hippocampal amnesia: A case study. *Neuropsychologia* 44(3): 489–506.

Clark SE and Gronlund SD (1996) Global matching models of recognition memory: How the models match the data. *Psychon. Bull. Rev.* 3(1): 37–60.

Curran T, Tepe KL, and Piatt C (2006) Event-related potential explorations of dual processes in recognition memory. In: Zimmer HD, Mecklinger A, and Lindenberger U (eds.) *Binding in Human Memory: A Neurocognitive Approach*, pp. 467–492. Oxford: Oxford University Press.

Daselaar SM, Fleck MS, Dobbins IG, Madden DJ, and Cabeza R (2006) Effects of healthy aging on hippocampal and rhinal memory functions: An event-related fMRI study. *Cereb. Cortex* 16(12): 1771–1782.

DeCarlo LT (2002) Signal detection theory with finite mixture distributions: Theoretical developments with applications to recognition memory. *Psychol. Rev.* 109: 710–721.

DeCarlo LT (2003) An application of signal detection theory with finite mixture distributions to source discrimination. *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 767–778.

Diana RA, Reder LM, Arndt J, and Park H (2006) Models of recognition: A review of arguments in favor of a dual-process account. *Psychon. Bull. Rev.* 13(1): 1–21.

Donaldson W (1996) The role of decision processes in remembering and knowing. *Mem. Cognit.* 24: 523–533.

Dunn JC (2004) Remember-know: A matter of confidence. *Psychol. Rev.* 111: 524–542.

Egan JP (1958) Recognition memory and the operating characteristic. *USAF Operational Applications Laboratory Technical Note*. No. 58–51: 32. Hearing and Communication Laboratory, Indiana University.

Eichenbaum H, Otto T, and Cohen NJ (1994) Two functional components of the hippocampal memory system. *Behav. Brain Sci.* 17: 449–517.

Eichenbaum H, Yonelinas AP, and Ranganath C (2007) The medial temporal lobe and recognition memory. *Annu. Rev. Neurosci.* 30: 123–152.

Friedman D and Johnson R Jr. (2000) Event-related potential (ERP) studies of memory encoding and retrieval: A selective review. *Microsc. Res. Tech.* 51(1): 6–28.

Fortin NJ, Wright SP, and Eichenbaum H (2004) Recollection-like memory retrieval in rats is dependent on the hippocampus. *Nature* 431: 188–191.

Gillund G and Shiffrin RM (1984) A retrieval model for both recognition and recall. *Psychol. Rev.* 91: 1–67.

Glanzer M, Hilford A, and Kim K (2004) Six regularities of source recognition. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 1176–1195.

Glanzer M, Kim K, Hilford A, and Adams JK (1999) Slope of the receiver-operating characteristic in recognition memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 500–513.

Green DM (1960) Psychoacoustics and detection theory. *J. Acoust. Soc. Am.* 32: 1189–1203.

Green DM and Swets JA (1966) *Signal Detection Theory and Psychophysics*. Oxford, England: Wiley.

Healy MR, Light LL, and Chung C (2005) Dual-process models of associative recognition in young and older adults: Evidence from receiver operating characteristics. *J. Exp. Psychol. Learn. Mem. Cogn.* 31: 768–788.

Heathcote A (2003) Item recognition memory and the receiver operating characteristic. *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 1210–1230.

Hilford A, Glanzer M, Kim K, and DeCarlo LT (2002) Regularities of source recognition: ROC analysis. *J. Exp. Psychol. Gen.* 131(4): 494–510.

Hintzman DL (1984) MINERVA 2: A simulation model of human memory. *Behav. Res. Methods Instruments Comput.* 16(2): 96–101.

Hirshman E and Master S (1997) Modeling the conscious correlates of recognition memory: Reflections on the remember-know paradigm. *Mem. Cognit.* 25(3): 345–351.

Hoffman HG (1997) Role of memory strength in reality monitoring decisions: Evidence from source attribution biases. *J. Exp. Psychol. Learn. Mem. Cogn.* 23(2): 371–383.

Jacoby LL (1991) A process dissociation framework: Separating automatic from intentional uses of memory. *J. Mem. Lang.* 30: 513–541.

Johnson MK, Hashtroudi S, and Lindsay DS (1993) Source monitoring. *Psychol. Bull.* 114(1): 3–28.

Kelley R and Wixted JT (2001) On the nature of associative information in recognition memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 701–722.

Krantz DH (1969) Threshold theories of signal detection. *Psychol. Rev.* 76: 308–324.

Lampinen JM, Odegard TN, and Neuschatz JS (2004) Robust recollection rejection in the memory conjunction paradigm. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 332–342.

Luce RD (1963) A threshold theory for simple detection experiment. *Psychol. Rev.* 70: 61–79.

Macho S (2004) Modeling associative recognition: A comparison of two-high-threshold, two-high-threshold signal detection, and mixture distribution models. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 83–97.

Macmillan NA and Creelman CD (1991) *Detection Theory: A User's Guide*. New York: Cambridge University Press.

Macmillan NA and Creelman CD (2005) *Detection Theory: A User's Guide*, 2nd edn. New York: Cambridge University Press.

Malmberg KJ (2002) On the form of ROCs constructed from confidence ratings. *J. Exp. Psychol. Learn. Mem. Cogn.* 28: 380–387.

Malmberg KJ and Xu J (2006) The influence of averaging and noisy decision strategies on the recognition memory ROC. *Psychon. Bull. Rev.* 13(1): 99–105.

Mandler G (1980) Recognizing: The judgment of previous occurrence. *Psychol. Rev.* 87(3): 252–271.

Manns JR, Hopkins RO, Reed JM, Kitchener EG, and Squire LR (2003) Recognition memory and the human hippocampus. *Neuron* 37(1): 171–180.

Marsh RL and Bower GH (1993) Eliciting cryptomnesia: Unconscious plagiarism in a puzzle task. *J. Exp. Psychol. Learn. Mem. Cogn.* 19(3): 673–688.

McClelland JL, McNaughton BL, and O'Reilly RC (1995) Why there are complementary learning systems in the hippocampus and neocortex: Insights from the successes and failures of connectionist models of learning and memory. *Psychol. Rev.* 102(3): 419–457.

Mecklinger A (2000) Interfacing mind and brain: A neurocognitive model of recognition memory. *Psychophysiology* 37: 565–582.

Murdock BB (1965) Signal-detection theory and short-term memory. *J. Exp. Psychol.* 70: 443–447.

Murdock BB (1974) *Human Memory: The Theory and Data*. Hillsdale, NJ: Erlbaum.

Murdock BB (1993) TODAM2: A model for the storage and retrieval of item, associative, and serial-order information. *Psychol. Rev.* 100: 183–203.

Norman KA and O'Reilly RC (2003) Modeling hippocampal and neocortical contributions to recognition memory: A complementary-learning-systems approach. *Psychol. Rev.* 110: 611–646.

Norman DA and Wickelgren WA (1965) Short-term recognition memory for single digits and pairs of digits. *J. Exp. Psychol.* 70: 479–489.

O'Reilly RC and Rudy JW (2001) Conjunctive representations in learning and memory: Principles of cortical and hippocampal function. *Psychol. Rev.* 108(2): 311–345.

Parks CM (2007) The role of noncriterial recollection in estimating recollection and familiarity. *J. Mem. Lang.* 57: 81–100.

Parks CM and Yonelinas AP (2007) Moving beyond pure signal-detection models: Comment on wixted (2007). *Psychol. Rev.* 114: 188–201.
Parks TE (1966) Single-detectability theory of recognition-memoru performance. *Psychol. Rev.* 73: 44–58.
Qin J, Raye CL, Johnson MK, and Mitchell KJ (2001) Source ROCs are (typically) curvilinear: Comment on Yonelinas (1999). *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 89–102.
Ratcliff R, McKoon G, and Tindall M (1994) Empirical generality of data from recognition memory receiver-operating characteristic functions and implications for the global memory models. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 763–785.
Ratcliff R, Sheu C, and Gronlund SD (1992) Testing global memory models using ROC curves. *Psychol. Rev.* 99: 518–535.
Reder LM, Nhouyvanisvong A, Schunn CD, Ayers MS, Angstadt P, and Hiraki K (2000) A mechanistic account of the mirror effect for word frequency: A computational model of remember-know judgments in a continuous recognition paradigm. *J. Exp. Psychol. Learn. Mem. Cogn.* 26(2): 294–320.
Rotello CM, Macmillan NA, and Reeder JA (2004) Sum-difference theory of remembering and knowing: A two-dimensional signal-detection model. *Psychol. Rev.* 111: 588–616.
Rotello CM, Macmillan NA, and Van Tassel G (2000) Recall-to-reject in recognition: Evidence from ROC curves. *J. Mem. Lang.* 43: 67–88.
Rugg MD, Allan K, and Birch CS (2000) Electrophysiological evidence for the modulation of retrieval orientation by depth of study processing. *J. Cogn. Neurosci.* 12(4): 664–678.
Rugg MD and Yonelinas AP (2003) Human recognition memory: A cognitive neuroscience perspective. *Trends Cogn. Sci.* 7: 313–319.
Sherman SJ, Atri A, Hasselmo ME, Stern CE, and Howard MW (2003) Scopolamine impairs human recognition memory: Data and modeling. *Behav. Neurosci.* 117(3): 526–539.
Slotnick SD, Klein SA, Dodson CS, and Shimamura AP (2000) An analysis of signal detection and threshold models of source memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1499–1517.
Slotnick SD and Dodson CS (2005) Support for a continuous (single-process) model of recognition memory and source memory. *Mem. Cognit.* 33: 151–170.
Swets JA (1961) Is there a sensory threshold? *Science* 134: 168–177.
Swets JA, Tanner WP Jr., and Birdsall TG (1961) Decision processes in perception. *Psychol. Rev.* 68: 301–340.
Tanner WP Jr. (1956) Theory of recognition. *J. Acoust. Soc. Am.* 28: 882–888.
Tanner WP Jr. and Swets JA (1954) A decision-making theory of visual detection. *Psychol. Rev.* 61: 401–409.
Tulving E (1985) Memory and consciousness. *Can. Psychol.* 26: 1–12.
Wickelgren WA (1968) Testing two-state theories with operating characteristics and a posteriori probabilities. *Psychol. Bull.* 69(2): 126–131.
Wais PE, Wixted JT, Hopkins RO, and Squire LR (2006) The hippocampus supports both the recollection and the familiarity components of recognition memory. *Neuron* 49(3): 459–466.
Wickens TD (2002) *Elementary Signal Detection Theory*. New York: Oxford University Press.
Wixted JT (2007) Dual-process theory and signal-detection theory of recognition memory. *Psychol. Rev.* 114: 152–176.
Wixted JT and Stretch V (2004) In defense of the signal detection interpretation of remember/know judgments. *Psychon. Bull. Rev.* 11: 616–641.
Yonelinas AP (1994) Receiver-operating characteristics in recognition memory: Evidence for a dual-process model. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 1341–1354.
Yonelinas AP (1997) Recognition memory ROCs for item and associative information: The contribution of recollection and familiarity. *Mem. Cognit.* 25(6): 747–763.
Yonelinas AP (1999a) The contribution of recollection and familiarity to recognition and source-memory judgments: A formal dual-process model and an analysis of receiver operating characteristics. *J. Exp. Psychol. Learn. Mem. Cogn.* 25(6): 1415–1434.
Yonelinas AP (1999b) Recognition memory ROCs and the dual-process signal-detection model: Comment on Glanzer, Kim, Hilford, and Adams (1999). *J. Exp. Psychol. Learn. Mem. Cogn.* 25(2): 514–521.
Yonelinas AP (2001) Consciousness, control, and confidence: The 3 Cs of recognition memory. *J. Exp. Psychol. Gen.* 130(3): 361–379.
Yonelinas AP (2002) The nature of recollection and familiarity: A review of 30 years of research. *J. Mem. Lang.* 46(3): 441–517.
Yonelinas AP, Dobbins I, Szymanski MD, Dhaliwal HS, and King L (1996) Signal-detection, threshold, and dual-process models of recognition memory: ROCs and conscious recollection. *Conscious. Cogn.* 5: 418–441.
Yonelinas AP and Jacoby LL (1995) The relation between remembering and knowing as bases for recognition: Effects of size congruency. *J. Mem. Lang.* 34: 622–643.
Yonelinas AP, Kroll NEA, Dobbins I, Lazzara M, and Knight RT (1998) Recollection and familiarity deficits in amnesia: Convergence of remember-know, process dissociation, and receiver operating characteristic data. *Neuropsychology* 12: 323–339.
Yonelinas AP, Kroll NE, Dobbins IG, and Soltani M (1999) Recognition memory for faces: When familiarity supports associative recognition judgments. *Psychon. Bull. Rev.* 6(4): 654–661.
Yonelinas AP, Kroll NE, Quamme JR, et al. (2002) Effects of extensive temporal lobe damage or mild hypoxia on recollection and familiarity. *Nat. Neurosci.* 5(11): 1236–1241.
Yonelinas AP, Regehr G, and Jacoby LL (1995) Incorporating response bias in a dual-process theory of memory. *J. Mem. Lang.* 34(6): 821–835.
Yonelinas AP, Quamme JR, Widaman KF, Kroll NE, Sauve MJ, and Knight RT (2004) Mild hypoxia disrupts recollection, not familiarity. *Cogn. Affective Behav. Neurosci.* 4(3): 393–400; discussion 401–406.

# 2.24 Memory Search: A Matter of Time

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## 2.24.1 Introduction

> In short, we make search in our memory for a forgotten idea, just as we rummage our house for a lost object. In both cases we visit what seems to us the probable neighborhood of that which we miss. We turn over the things under which, or within which, or alongside of which, it may possibly be; and if it lies near them, it soon comes to view. (William James, 1890: 290)

In most instances, memory retrieval occurs in a seemingly automatic and effortless fashion, as when we recognize an acquaintance or type in a password. These successful, and underappreciated, acts of retrieval suggest memory is a direct, immediate, content-addressable type of filing system. That is, we do not appear to engage in a search of memory in the literal sense of the term. There are occasions, though, when the desired information does not come easily to mind, and we then must engage in a more conscious and effortful interrogation of memory, as in William James' example above. Everyone has, from time to time, tried to remember where they parked their car in a busy lot, or what that funny joke was they heard last week. A salient feature of these types of retrieval attempts is that they seem to involve a search of memory that takes some appreciable amount of time.

Many researchers have measured response time (or reaction time or response latency; hereafter termed RT) in different memory tasks as a means to try to identify the nature of the underlying retrieval processes.

The measurement and interpretation of response time have a long history. For example, Donders (1868/1969) proposed a method to measure the time it takes to complete a particular set of mental processes, and Jastrow (1890) argued that, by working backward from response time, one might be able to infer the particular processing structures that were used to perform the task. Luce (1986) and Welford (1980) discussed the broader use of response time to study cognitive processes and the detailed methods used in the analyses of response times.

In this chapter we review the analyses of RT for different tests of explicit memory as a way to examine and compare different characteristics of intentional memory search and retrieval processes. Measures of RT and response accuracy are sometimes viewed as complementary because they often show the same effects, suggesting that they are reflections of the same underlying processes. These measures, however, are not equivalent because some variables can have large effects on accuracy but have little or no effect on response latency (e.g., Rohrer and Wixted, 1994), and RT can be highly informative when accuracy is perfect (e.g., Mewhort and Johns, 2000). The problem of speed–accuracy tradeoffs can also lead to incorrect interpretations of RT if error rates across conditions are not considered (e.g., Pachella, 1974; Wickelgren, 1977). Thus, one should be cautious in considering only one of these two measures of performance. See Kahana and Loftus (1999) for a review and comparison of accuracy and RT in the study of memory. The measurement and analysis of RT include mean RT, the analysis of RT distributions, and speed–accuracy tradeoff functions. These measures will be considered in turn for the principal tasks that have been used to study different features of human memory – item recognition, associative recognition, cued recall, and free and serial recall.

## 2.24.2 Item Recognition

### 2.24.2.1 Item Recognition for Subspan Lists

The beauty of Helen of Troy is said to have launched a thousand ships. It might also be the case that Sternberg's (1966) classic study of memory search in short-term memory launched a thousand experiments. In Sternberg's procedure, participants view short lists of items (usually one to six) presented one at a time. Each list is followed by either an old or new test probe. Participants are instructed to respond whether or not the probe is a member of the preceding study set as quickly as possible while minimizing errors. In the varied-set version of this procedure there is one test following each list, and list length varies over trials. In the fixed-set variant, a given list is prememorized and followed by a series of test probes, and this process is repeated for lists of different lengths. Because the lists are less than the span of immediate memory, accuracy is very high, and RT is the primary dependent measure.

Sternberg found the same pattern of results in both the varied- and fixed-set versions of this task: RT increased in a linear fashion with the number of items in the memory set for both correct old and new decisions. This pattern of results has been replicated many times by many different researchers. An example of the linear RT set size function for the varied-set version of the Sternberg task is shown in the left panel of **Figure 1**. The linearity of the memory set function is not affected by considerable practice at the task (Kristofferson, 1972) and is found for a wide range of stimulus materials – letters, digits, faces, geometric shapes, colors, and words (cf. Sternberg, 1975), suggesting that this result reflects a basic property of the short-term memory search process.

Sternberg (1966, 1969) proposed that these results reflect a high-speed serial search process. That is, the probe item is compared to each item in the memory set one at a time. The time for each individual comparison is given by the slope of the function relating RT to set size, which is typically in the range of 35 to 40 ms per item. Such a search rate is indeed extremely fast – in the order of 25 items per second. The comparison process was also assumed to be exhaustive such that the probe is compared with every item in the memory set before a single yes or no match decision is made. This assumption is based on the finding that the slopes of the correct 'yes' and 'no' memory set functions are parallel. An exhaustive search process would seem inefficient compared to a self-terminating search process that would end when a positive match is found. Sternberg argued, though, that an exhaustive search is more efficient because it requires only one match decision following the entire comparison process as opposed to a decision after each individual comparison that would be required for a self-terminating serial search process.

The plausibility of Sternberg's exhaustive serial search process was later called into question, not on logical grounds but on empirical grounds. One problem concerned the characteristics of the underlying RT distributions. Schneider and Shiffrin (1977) noted that the variance increased more for positive than for negative responses at larger set sizes. An exhaustive search process predicts that, like mean RT, the

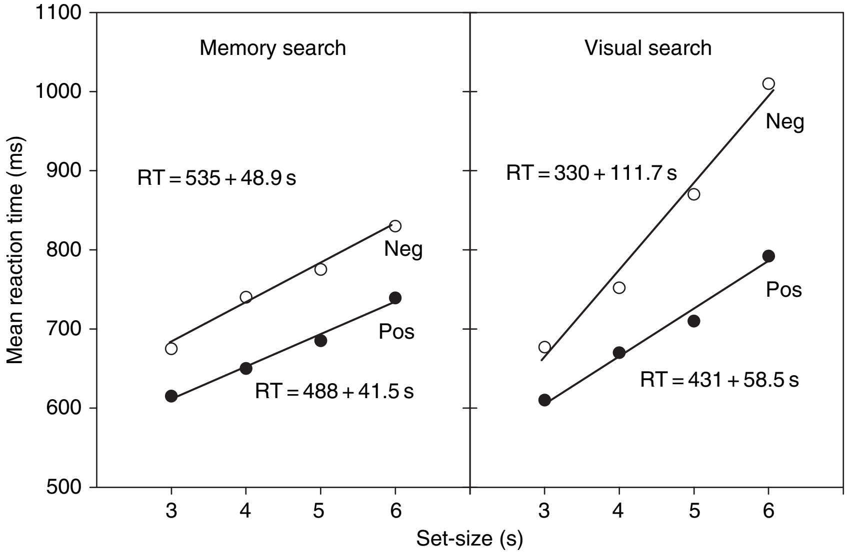


**Figure 1** This figure shows mean response time (RT) for correct positive (solid circles) and correct negative (open circles) responses as a function of set size for Sternberg's (1966) short-term search task (left panel) and Neisser's (1963) visual search task (right panel). The data are from Hockley WE (1984) Analysis of response time distributions in the study of cognitive processes. *J. Exp. Psychol. Learn. Mem. Cogn.* 10: 598–615; used with permission.

variance of the RTs should be similar for old and new responses.

Hockley (1984; see also Hockley and Corballis, 1982) analyzed RT distributions in the Sternberg paradigm using the ex-Gaussian distribution to describe the shape and the changes of the RT distributions with memory set size. Ratcliff and Murdock (1976) showed that the ex-Gaussian distribution provides a very good description of observed RT distributions for a number of recognition memory phenomena. It has subsequently been used by investigators to characterize RT distributions in a variety of cognitive tasks (e.g., the Stroop effect; Heathcote et al., 1991).

The ex-Gaussian distribution is the convolution of normal and exponential distributions and is described by the following equation:

$$f(t) = \frac{\mathrm{e}^{-(\mathrm{t}-\mu)/\tau+\sigma^2/2\tau^2}}{\tau\sqrt{2\pi}} \int_{-\infty}^{(\mathrm{t}-\mu)/\sigma-\sigma/\tau} \mathrm{e}^{-\frac{y^2}{\mathrm{d}y}}$$

where $\mu$ (mu) and $\sigma$ (sigma) represent the mean and standard deviation, respectively, of the normal distribution component, and $\tau$ (tau) represents the parameter and mean of the exponential distribution component. Although the equation appears quite daunting, this distribution is much simpler conceptually. Imagine a normal distribution, and then extend or stretch out the right tail of this distribution (examples are shown in **Figure 2** and in **Figures 8 and 12** later in the chapter). In general terms, mu reflects the left or leading edge of the RT distribution, while tau reflects the elongated right tail, or the positive skew, of the distribution. Thus, mu and tau quantify two important properties of RT distributions, namely, the minimum or fastest RTs and the spread of the distribution determined by the slowest responses.

Hockley (1984) contrasted the nature of the RT distributions in the Sternberg memory search task with a visual search task. The visual search task was based on the search experiments reported by Neisser (1963) in which participants are first presented with a target letter followed by a vertically presented set of three to six letters. Participants determined whether or not the target item was contained in the search set. The RT set size functions for positive and negative responses are shown in the right panel of **Figure 1**. The results of the visual search task were consistent with a self-terminating serial search process where the visual search proceeds from the top to the bottom of the column of letters. Correct mean RT was a linear function of the size of the search set, the slope of the function for negatives was almost twice as steep as that for positives, and the serial position functions showed a recency gradient.

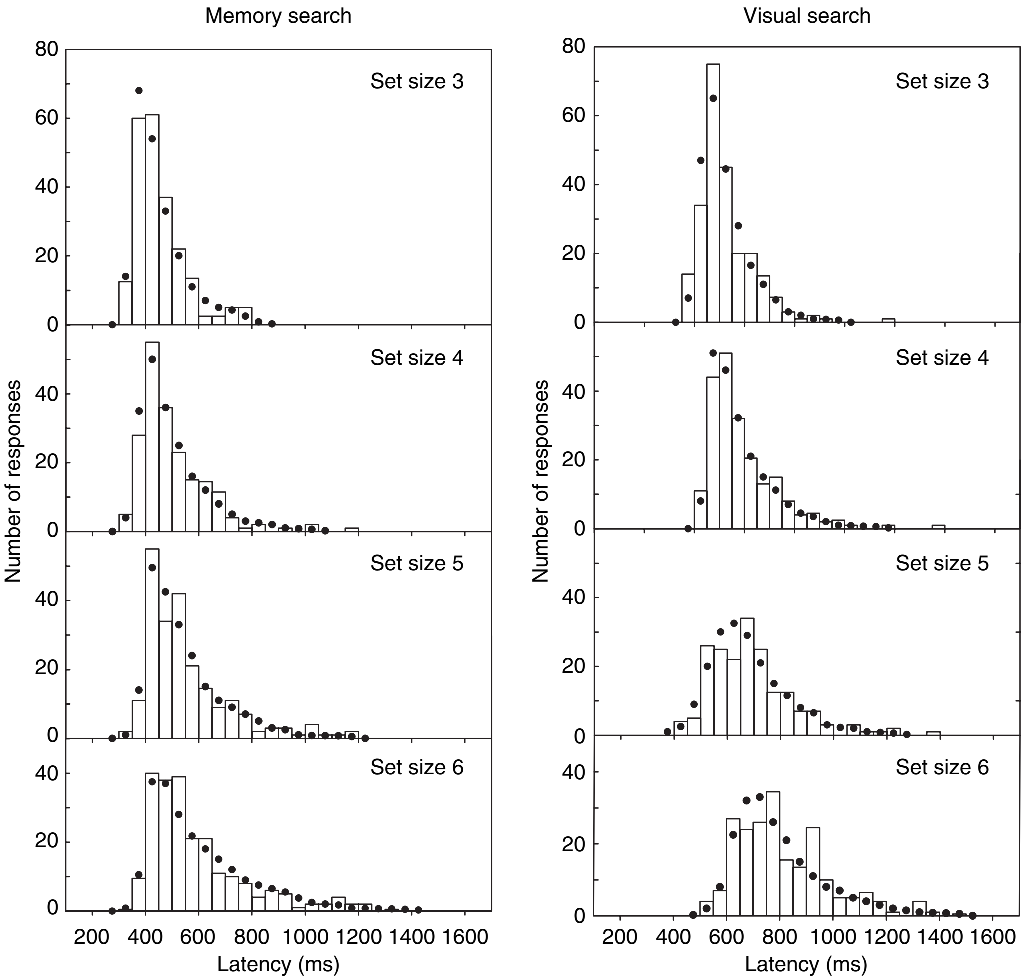


**Figure 2** The bar graphs show the observed RT distributions for correct negative responses for one participant for the memory search task and the visual search task. The fits of the ex-Gaussian distribution are shown by the dots. Data are from Hockley WE (1984) Analysis of response time distributions in the study of cognitive processes. *J. Exp. Psychol. Learn. Mem. Cogn.* 10: 598–615; used with permission.

The analysis of the RT distributions for the visual search task were also consistent with a self-terminating serial search process, as the increase in mean RT was largely captured by increases in the parameter mu, which reflects changes in the leading edge of the latency distribution, or the fastest responses. In contrast, while the pattern of mean RTs in the memory search task replicated Sternberg's findings as shown in **Figure 1**, the increase in mean RT was largely seen in the tau parameter, which reflects the increasing skew of the RT distribution, or an increase in the slower responses.

The differences in the changes of the underlying distributions in the visual and memory tasks are illustrated in **Figure 2**. This figure shows the observed RT distributions and the fits of the convolution model for correct negative responses in each task for one of the six participants in the experiment. In the visual search task the entire distribution shifts to the right as set size increases. Thus the minimum as well as the maximum RTs increase with the number of items in the search set. In contrast, the minimum or fastest RTs change very little in the memory search task, a result that is inconsistent with a serial search process. These results for the Sternberg task have been replicated more recently by Ashby et al. (1993).

A second empirical problem for Sternberg's serial search hypothesis concerned the findings of serial position effects (e.g., Corballis, 1967; Burrows and Okada, 1971; Corballis et al., 1972; Ratcliff, 1978; Aube and Murdock, 1974; Monsell, 1978; Murdock and Franklin, 1984; McElree and Dosher, 1989).

Contrary to predictions of exhaustive scanning, mean RT for yes decisions was influenced by the position of the target item in the memory set. Generally, except for a small primacy effect, these studies showed that mean RT increased with decreasing recency of the positive test probe. Monsell (1978) demonstrated that when serial position is defined in terms of recency, or the number of items intervening between study and test (test lag), the serial position functions for memory set sizes of one to five were the same for all positions except the primacy item. The coexistence of both serial-position and set-size effects led to the suggestion that set-size effects arise due to the effects of serial position (Murdock, 1971, 1985; Monsell, 1978).

McElree and Dosher (1989) replicated Monsell's (1978) recency results using the response signal version of the speed–accuracy trade-off (SAT) procedure. This procedure provides a way to examine the time course of retrieval (Wickelgren and Corbett, 1977; Corbett and Wickelgren, 1978; Wickelgren et al., 1980; Dosher, 1981). In this paradigm retrieval is interrupted at different temporal intervals (typically between 0.1 and 3 s) after the probe is presented by having participants make a recognition decision as soon as the cue to respond is given. By examining performance over the different intervals one can assess the increase in accuracy as retrieval time increases until accuracy reaches an asymptote. SAT functions are characterized by three parameters: an intercept or starting point of the function, the rate of rise from chance accuracy to asymptotic or final level of accuracy, and the asymptotic level of accuracy. The intercept provides a measure of when information first becomes available, the rise parameter indexes the rate of accrual of information over time, and the asymptote reflects the maximum level of accuracy. **Figure 3** shows McElree and Dosher's SAT functions for different serial positions for memory set sizes of 3 and 5. These functions show that serial position primarily affects the asymptotic accuracy of recognition performance. The differences in the retrieval dynamics of the functions (the intercept and rate parameters) were restricted to differences between probes from the most recent serial position (the last study item before the test probe) and all other probes. Thus, with the exception of the last item, serial position influenced accuracy but not the speed of retrieval.

One criticism of the response signal procedure is that it cannot distinguish between variable all-or-none processing and continuous accumulation of information. That is, if all of the retrieved information

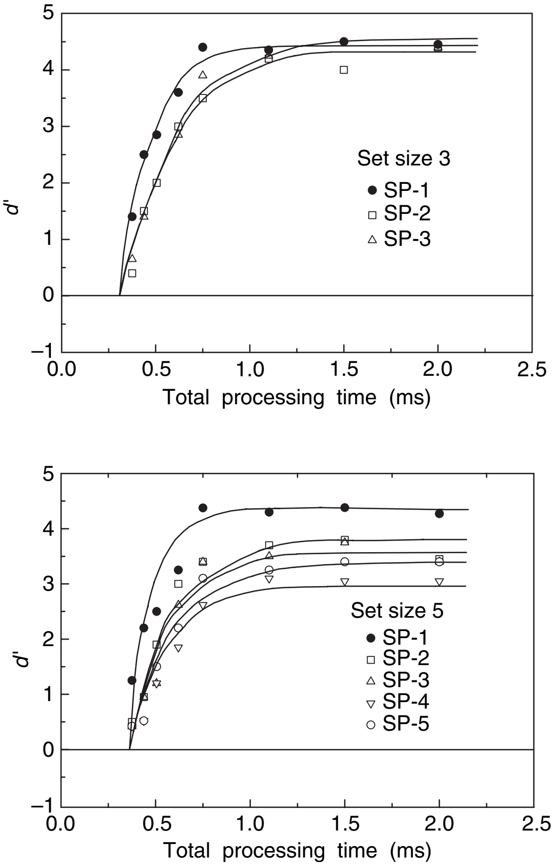


**Figure 3** This figure shows mean d' values (a measure of discrimination or sensitivity from signal detection theory; cf. Macmillan and Creelman, 2005) as a function of total processing time for each serial position for set size 3 (top panel) and set size 5 (bottom panel). The solid lines represent the best-fitting exponential SAT functions. The results are from McElree B and Dosher BA (1989) Serial position and set size in short-term memory: The time course of recognition. *J. Exp. Psychol. Gen.* 118: 346–373; used with permission.

becomes available at one time and this time is variable, the SAT curves from the response signal procedure would still increase in a gradual fashion. Meyer et al. (1988) introduced a variant of the response signal procedure – speed–accuracy decomposition (SAD) – as a way to address this problem. In the SAD procedure regular (no signal) trials are randomly interspersed with signal trials, and the RT distributions are compared (see Ratcliff (1988) and Kahana and Loftus (1999) for a discussion of these SAT procedures). These results provide support for the view that information accumulates continuously.

A third problem for Sternberg's model was the finding of repetition effects (Burrows and Okada, 1971; Baddeley and Ecob, 1973). Responses to items that were repeated in the memory set (e.g., 9 1 9 3) are faster than responses to nonrepeated items. Most damaging, perhaps, for Sternberg's serial search account were the findings of recency effects for negative probes. Both RT and accuracy suffer the more recently a negative probe on a current trial had been presented as a memory set item on a previous trial (e.g., Atkinson et al., 1974; Monsell, 1978; Hockley and Corballis, 1982; McElree and Dosher, 1989). This finding demonstrates that recognition decisions are influenced by the longer-term presentation history of the items outside the current short-term memory set, a finding that is not easily reconcilable with serial search models of immediate memory (Monsell, 1978; Ratcliff, 1978).

Van Zandt and Townsend (1993) evaluated the different classes of exhaustive and self-terminating search models in light of the results observed in the Sternberg paradigm and found that exhaustive processing models were not tenable. They concluded that self-terminating models provide the best description of rapid visual and memory search processes. A number of researchers have proposed versions of strength-based models as alternatives to Sternberg's original model (e.g., Wickelgren and Norman, 1966; Baddeley and Ecob, 1973; Murdock, 1985; McElree and Dosher, 1989). Ratcliff's (1978) diffusion model is one of the most developed and influential models illustrating this approach.

In Ratcliff's (1978) theory of memory retrieval the recognition test probe is compared to all of the items in the search set in parallel. Evidence is accumulated for each comparison based on the degree of relatedness between the probe and the memory item. This process is modeled by a continuous random walk process; positive evidence causes the random walk to approach an upper match boundary, while negative evidence drives the process downward toward a nonmatch boundary. A positive recognition decision is made when one of the comparison processes reaches the match boundary. If all the comparison processes terminate at the nonmatch boundary a negative decision is made. Ratcliff showed that this model can produce all of the findings observed in the Sternberg paradigm: linear and parallel RT set size functions, serial position effects, and the appropriate characteristics of the RT distributions and the SAT functions.

### 2.24.2.2 The Extralist Feature Effect

In Ratcliff's (1978) retrieval model, the latency of correct negative decisions depends on the slowest mismatch between the test probe and the items in memory that enter into the comparison process. Thus, negative decisions are treated as a default option that is reached when there is insufficient evidence (or strength or familiarity) to support a positive decision. Mewhort and Johns (2000; Johns and Mewhort, 2002, 2003) have recently challenged this notion. They proposed instead that correct rejections are based on information in the probe that contradicts the information represented in the study set.

Mewhort and Johns (2000) used stimuli that comprised a small number of features with finite values (e.g., a red star, a yellow triangle, etc.). Like Sternberg (1969), Mewhort and Johns used subspan study lists, and they also conditionalized the data on sure (or high confident) recognition responses to ensure that they were examining retrieval based on accurate encoding of the study items. The use of two-dimensional stimuli allowed the researchers to vary the similarity between the probe and the studied or target items. In the example given by Mewhort and Johns, a participant studies the following set of items: a blue cross, a red triangle, and a green circle. A yellow diamond would be a negative probe that does not share any features with the studied items (condition 0:0), a yellow cross or a red diamond would be a negative probe that shares one of its two features with the study set (condition 1:0), and a blue triangle or a green cross would be a negative probe that shares both of its features with the study set (condition 1:1). The similarity of the negative probe could also be varied in terms of the number of study items that share the same feature. For example, if two of the study items had the feature red, then a red star lure would share a repeated feature of the study set (condition 2:0).

Mewhort and Johns (2000; Johns and Mewhort, 2002, 2003) found that participants were fastest to correctly reject negative probes when they did not share a feature with the study set (the extralist feature effect) and became progressively slower as the number of shared features increased. That is, condition 0:0 was faster than condition 1:0, which in turn was faster than condition 1:1. In addition, the number of times a probe feature was studied did not affect RT when an extralist feature was present. That is, mean RT in condition 2:0 was similar to that of condition 1:0. This finding poses problems for familiarity-based accounts of recognition. Mewhort and Johns also showed that the extralist feature effect could be found using words as stimuli where the manipulated features were the letters within the words, and also for prememorized lists that exceeded memory span.

As Mewhort and Johns argued, these results do not support the view that correct rejections are a default decision that occurs when insufficient evidence accrues to support a positive response. Rather, the extralist feature effect shows a clear role of contradiction in recognition decisions, at least when the information supporting contradiction is available, and also perhaps when the memory set is very well-defined.

### 2.24.2.3 Item Recognition for Supraspan Lists

Burrows and Okada (1975) measured RT for memorized lists of items that varied from 2 to 20 in length. RT was an increasing function of list length. Their results were best fit by bilinear functions with the break point occurring between lists of six and eight items, the traditional measure of memory span, and they argued that these results support the view that memory search processes are different above and below short-term memory span. Burrows and Okada noted, though, that a single continuous logarithmic function also provided a good description of the relationship between RT and list length. Similar results were found by Banks and Fariello (1974), who tested memory for lists of pictures of common scenes that varied from 2 to 24.

Hockley and Corballis (1982) replicated and extended Burrows and Okada's results. They also compared conditions in which negative probes were and were not repeated across lists in a session. Their results are presented in **Figure 4**. Again, mean RT increased as a function of memory set size, and a bilinear function with the break point at memory span provided a better fit than a single logarithmic function. When negatives were repeated, the slopes of each limb of the bilinear function and the rate constant of the logarithmic function were almost doubled. The fact that this manipulation had a similar effect on both subspan and supraspan list lengths suggests that these results reflect the operation of one retrieval process rather than retrieval from different memory systems.

Similar results have also been observed in the continuous recognition paradigm. In this procedure items are repeated in a long list of items, and participants make a recognition decision for each list presentation. Thus, an item is 'new' on its first appearance in the list and 'old' on its second presentation. Accuracy decreases and response latency increases as a function of the number of items, or test lag, between the first and second presentations of an item. Hockley (1984) found that a logarithmic function provided a good description of the increase in RT with test lag that varied from 1 to 24 intervening items. Moreover, he also found that both between-list and within-list stimulus manipulations (nouns versus nonnouns) influenced the slope of the logarithmic function with no appreciable effect on the intercept, whereas item repetition decreased the intercept with little effect on the slope.

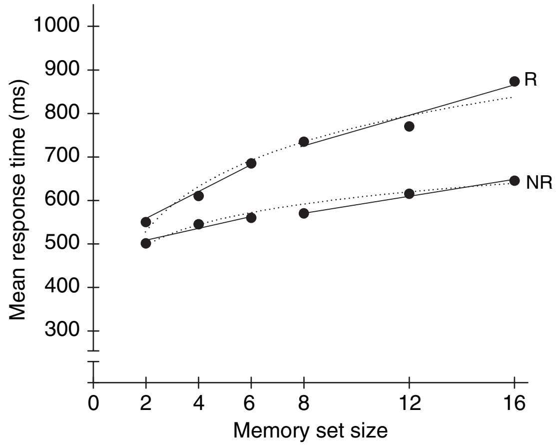


**Figure 4** This figure shows mean response time (RT) as a function of memory set size (M) for lists with repeated negatives (R) and lists with nonrepeated negatives (NR). The dashed lines represent the best fitting logarithmic functions ($RT(R) = 415 + 159 \log_e M$; $RT(NR) = 445 + 81 \log_e M$), and the solid lines show each limb of the best-fitting bilinear functions with the breakpoint at the estimate of short-term memory span ($RT(R) = 468 + 38M$, and $RT(NR) = 471 + 20M$ for set sizes 2, 4, and 6; $RT(R) = 605 + 17M$, and $RT(NR) = 522 + 10M$ for set sizes 8, 12, and 16).

Findings from the response deadline SAT procedure further support a recency or strength-based view of recognition memory over both the subspan and supraspan range. Wickelgren et al. (1980) used a single-item probe recognition task to examine the temporal dynamics of retrieval for different serial positions of 16-item lists. They fit SAT retrieval functions for three subspan serial positions (16, 15, and 14, or the last three items of the list), and three supraspan sets of items (serial positions 13–11, 10–6, and 5–3). Asymptotic accuracy decreased monotonically with the decreasing recency of the test probe's serial position, indicating that memory strength declines systematically over this range. Retrieval speed (as estimated by the intercept and rate parameters of the SAT functions), however, was constant across all serial positions exception for the last (most recent) item, which was processed 50% faster than the items from all of the other serial positions. Wickelgren et al. concluded that retrieval speed is constant except for the last item, which is in a privileged state of active awareness. (See McElree, 2001, for further evidence that the capacity of focal attention is limited to a very small number of representations, perhaps just one.)

### 2.24.2.4 Short-Term versus Long-Term Memory

Sternberg (1966) developed his subspan item recognition paradigm in order to study memory search processes in short-term or immediate memory. But is the distinction between short-term and long-term memory relevant to item recognition perfomance? When list length has been varied above and below memory span, both bilinear functions with the breakpoint at or near memory span, and continuous functions provide a good description of the increase in RT with list length or the lag between study and test (e.g., Banks and Fariello, 1974; Burrows and Okada, 1975; Hockley, 1984). Which function provides the more appropriate description of changes in RT with list length?

Three findings indicate that the continuous function provides the more meaningful description of recognition performance. First, the effects of repeating items from previous trials (e.g., Monsell, 1978; McElree and Dosher, 1989) show that recognition is not solely based on the current contents of short-term memory. Second, manipulations have similar effects on subspan and supraspan list lengths and have been shown to differentially affect the intercept and slope parameters of the continouous span functions (e.g., Hockley and Corballis, 1982; Hockley, 1984). Finally, results from the response-signal SAT procedure show that retrieval speed is constant below and above span except for the most recent item which appears to be in a privileged state of awareness (Wickelgren et al., 1980; McElree and Dosher, 1989; McElree, 2001). All of these results indicate that, with the possible exception of the most recent item, recognition proceeds in the same fashion above and below memory span.

### 2.24.2.5 Regularities of Item Recognition

Ratcliff and Murdock (1976) summarized a number of functional relationships between accuracy and response latency obtained in the study-test recognition paradigm. These relationships are shown in **Figure 5**. They provide a set of benchmarks that any model of recognition performance must be able to accommodate. In general, changes in mean RT mirror changes in accuracy. Accuracy increases while mean RT decreases with the confidence of the recognition decision. Accuracy and RT for high-confidence responses change in a complementary fashion as a function of output (test) and input (study) position and the number of study presentations of the items. Correct 'new' decisions (correct rejections) are almost as fast as correct 'old' decisions (hits). In addition, the changes in mean RT are seen to a greater extent in the tau parameter (the measure of skewness or variance) than in the mu parameter (minimum latencies) of the ex-Gaussian analysis of the RT distributions. As discussed previously, similar effects of recency, repetition, and list length effects, and changes in RT distributions and SAT functions have been observed in item recognition for subspan lists, indicating that these effects are basic characteristics of recognition memory.

Ratcliff (1978) showed that his diffusion model could not only fit the pattern of results found in the Sternberg paradigm, but also provide an impressive account of the accuracy and latency results obtained in the study-test paradigm and illustrated in **Figure 5**, as well as results from the prememorized list and continuous recognition procedures. Ratcliff's diffusion model is a formal theory of the retrieval and decision process, but it does not provide an account of how items are represented in memory or how they are compared. Nevertheless, the diffusion model can be incorporated into models that do make explicit assumptions concerning how items are represented and compared, such as Gillund and Shiffrin's (1984) search of associative memory (SAM) model and Hintzman's (1988) MINERVA 2 model.

A more recent regularity of recognition memory is the mirror effect (Glanzer and Adams, 1985, 1990). This effect refers to the finding that, when two classes of stimuli, A and B, are compared and class A is more accurately recognized than class B, the difference in accuracy is seen both in terms of a higher hit rate for class A old items and a lower false alarm rate for class A new items. If one thinks in terms of the underlying distributions representing the strength of the old and

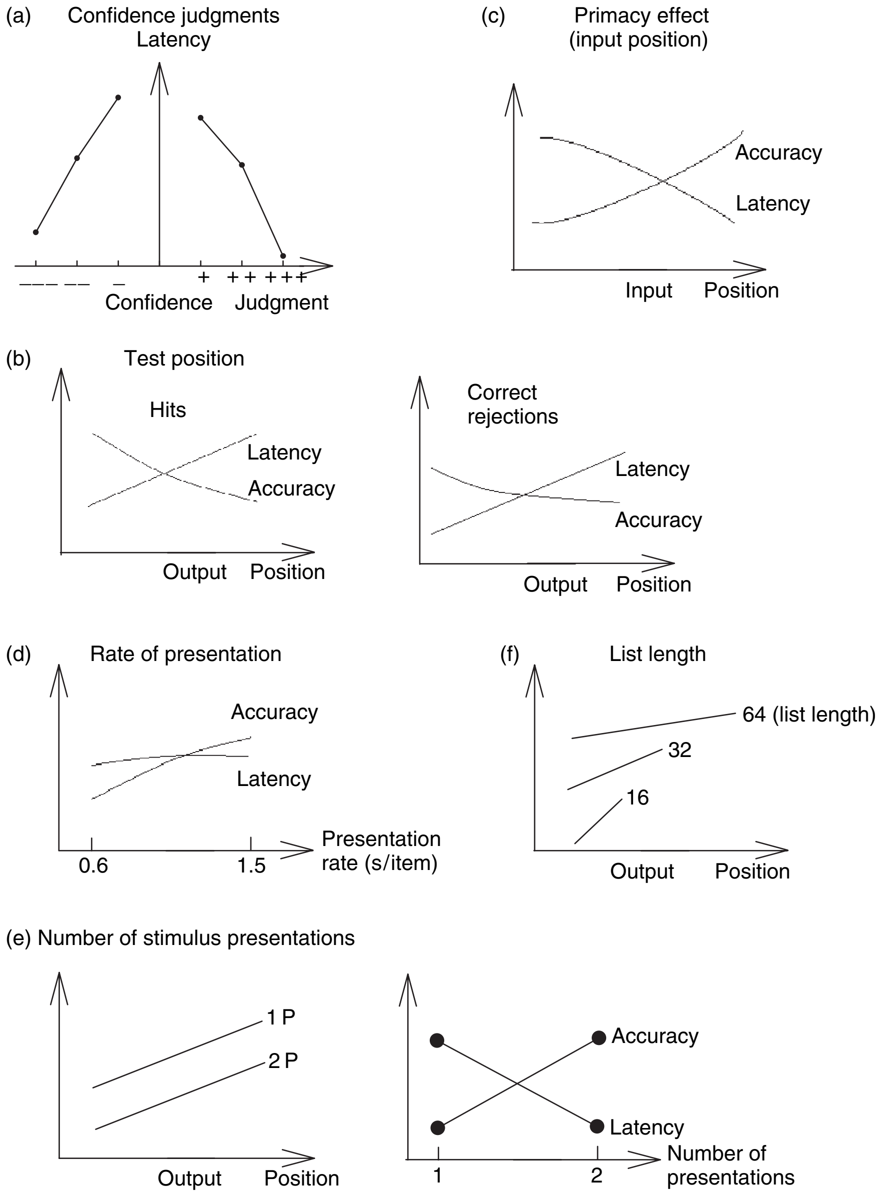


**Figure 5** This figure summarizes the functional relationships of recognition decisions described by Ratcliff R and Murdock BB Jr. (1976) Retrieval processes in recognition memory. *Psychol. Rev.* 83: 190–214; used with permission. These relationships show that: (a) mean RT decreases as confidence increases; (b) accuracy and latency vary inversely with test (output) position, (c) study (input) position, (d) presentation rate at study, and (e) number of presentations at study; and (f) the increase in response latency as a function of output position decreases as list length increases. (Note that relationships (b) through (f) are for high-confidence responses only.)

new items of each class (as assumed in signal detection theory), then the order of the class A and B new item distributions mirror the order of the class A and B old item distributions. The mirror effect is also reflected in the pattern of mean RTs for the correct 'old' (hits) and 'new' (correct rejections) responses of each stimulus class (Hockley, 1994). The comparison of low- and high-frequency words, where low-frequency words are more accurately recognized than high-frequency words, is a prototypical example of the mirror effect in item recognition.

The mirror effect posed a challenge for simple strength-based models of recognition memory, because these models cannot easily account for why, for example, low-frequency items have a lower average strength than high-frequency items when they are new, but have a higher average strength than high-frequency items after one study presentation. The mirror effect provided the impetus for a new generation of single-process models of recognition memory that could accommodate the mirror effect (e.g., Anderson and Milson, 1989; Shiffrin and Steyvers, 1997; McClelland and Chappell, 1998; Dennis and Humphreys, 2001; Murdock, 2003). The word-frequency mirror effect has also been taken as evidence in support of dual-process models of item recognition (Joordens and Hockley, 2000; Reder et al., 2000).

### 2.24.2.6 Dual-Process Views of Recognition

A debate that has received considerable attention has been waged between single-process theories of recognition decisions on the one hand (e.g., the global matching models of Murdock (1982), Gillund and Shiffrin (1984), and Hintzman (1988) and the more recent models of Shiffrin and Steyvers (1997), McClelland and Chappell (1998), and Dunn (2004)) and dual-process views on the other (e.g., Atkinson and Juola, 1973, 1974; Mandler, 1980; Jacoby, 1991; Yonelinas, 1994; Joordens and Hockley, 2000; Reder et al., 2000). Although single-process models differ in many interesting ways, they share a common assumption that recognition decisions are based on a single evidence dimension that has been variously characterized as memory or matching strength or familiarity. In contrast, the unifying assumption of dual-process theories is that recognition involves both familiarity and the recollection or retrieval of specific details of a prior experience (for recent reviews see Yonelinas, 2002; Diana et al., 2006).

No one questions that recollection can play a role in memorial decisions; indeed, a number of paradigms have been developed to examine the retrieval of specific details of the occurrence of past instances such as plurality discrimination (where participants must discriminate between old words such as *frog* and highly related distractors such as *frogs,* e.g., Hintzman and Curran, 1994; Rotello and Heit, 1999). Malmberg et al. (2004), for example, have proposed a version of Shiffrin and Steyvers' (1997) retrieving effectively from memory (REM) model that incorporates a recollection component for such cases. The controversial question is not about recollection *per se*, but rather whether recollection routinely plays an important role in the normal course of item recognition.

In the dual-process framework, it is generally assumed that familiarity-based processes occur in a rapid and automatic fashion. In contrast, recollection is a slower and more intentional retrieval process. Studies of the temporal dynamics of recognition decisions have provided evidence in support of this view. As discussed earlier, in the response-signal SAT procedure, participants must respond at different temporal deadlines during retrieval, allowing one to plot the growth of the accuracy of recognition decisions with increasing retrieval time. Studies using this procedure have shown that decisions that can be informed by familiarity alone, such as item recognition, can be made more accurately earlier than decisions that require retrieval of specific details such as source judgments (e.g., Hintzman and Caulton, 1997; Hintzman et al., 1998; McElree et al., 1999). These results are consistent with the view that familiarity is available very early after the presentation of the test probe, whereas recollection is a slower retrieval process. Another finding that indicates the early availability of familiarity is seen in false alarms to lures that are similar to studied items. These incorrect responses show an initial early increase and then a decrease with response lag (e.g., Dosher, 1984; Dosher and Rosedale, 1991; Hintzman and Curran, 1994), suggesting that the early responses are based only on familiarity. Somewhat later, item-specific information is retrieved that provides a basis for correctly rejecting similar lures.

Boldini et al. (2004) found a dissociation using the response-signal SAT procedure that they interpreted as further support for the dual-process view of recognition. Under incidental learning conditions, these investigators varied the level of processing of the items at study (pleasantness ratings that would promote deep processing versus maintenance rehearsal that supports only shallow encoding; cf. Craik and Lockhart, 1972) and whether or not the perceptual characteristics (modality) of the stimuli matched between study and test (auditory-visual vs. visual-visual presentations). Modality or perceptual match influenced recognition performance at the short response-signal delays (<300 ms), while level of processing affected accuracy at longer delays (>300 ms). Boldini et al. concluded that both a fast familiarity-based process and a slower recollection-based process contribute to recognition memory decisions.

A number of researchers have adopted Tulving's (1985) remember-know response procedure to distinguish between familiarity- and recollection-based recognition decisions. In this procedure, participants are instructed to classify their old decisions as either 'remember' if they recall any specific detail or details of the prior episode, or 'know' if the test item felt familiar but no specific details of the previous experience were recollected. Researchers have demonstrated that a number of variables differentially affect these two types of responses (see Gardiner and Richardson-Klavehn, 2000, for a comprehensive review). For example, elaborative rehearsal (deep processing) affects remember but not know responses, whereas maintenance rehearsal (shallow processing) affects know responses without influencing responses classified as remember (Gardiner et al., 1994). Such dissociations have been taken as evidence for the separate contributions of familiarity and recollection to recognition decisions.

This subjective response procedure, however, is not without its critics. Donaldson (1996) and Hirshman and Master (1997) have argued that remember and know responses reflect differences in confidence (or strength of evidence) rather than distinguishing between decisions that are based on two different types of memorial information. Extending this view, Dunn (2004) developed a signal-detection type model in which remember and know responses are derived from two different decision criteria that bisect a single dimension of familiarity. In this model a new decision would be made if the familiarity associated with the test probe was below the lower of the two decision criteria, and an old 'know' response would be made if the familiarity value exceeded the lower criterion. If the familiarity value exceeded the higher of the two criteria, the old decision would then be classified as 'remember.' Dunn showed that such a model can, with appropriate placement of the two decision criteria, account for all of the dissociations between remember and know responses that are taken as support for the dual-process view. In reply, dual-process theorists have questioned whether participants are capable of adjusting their decision criteria in each experimental condition in the manner that Dunn assumed in his model (Diana et al., 2006).

The interpretation of the latency of remember and know responses is also controversial. Remember responses have typically been found to be faster than know responses (Dewhurst and Conway, 1994; Dewhurst et al., 1998, 2006; Henson et al., 1999; Hockley et al., 1999). Wixted and Stretch (2004) have shown that a single-dimension signal-detection model of remember/know responses predicts just this result. In contrast, this finding would appear to be in conflict with the results obtained with the response-signal SAT procedure that shows that familiarity processes are faster than recollection, and with the predictions of dual-process theory. Yonelinas (2002), however, suggests that the slower latency of know responses is an artifact of the remember/know instructions. These instructions specify that a know response should be made when there is no contextual information available to support a remember response. As a consequence, participants must assess recollection before making a know response. Remember responses, in contrast, can be made as soon as any contextual details are retrieved.

A different dual-process interpretation of the latency of remember and know responses has been offered by Henson et al. (1999) and Dewhurst et al. (2006; see also Gardiner et al., 1999; Konstantinou and Gardiner, 2005). Henson et al. suggested that know decisions take longer because it is more difficult to make recognition decisions in the absence of the recollection of contextual details. Dewhurst et al. showed that slower know responses are found both when participants make a single timed remember/know/new decision (one-step procedure) and when the untimed remember-know decision follows a timed old/new response (two-step procedure). Perhaps more interestingly, know responses were also slower when the remember-know decisions were made retrospectively. In this experiment, test items were presented once, and participants made old/new decisions. The test items were then presented a second time, and the participants were asked to indicate whether their previous old/new decisions had been based on familiarity or recollection. The mean RT of the old decisions that were subsequently identified as based on recollection (796 ms) was faster than the old decisions later classified as know (930 ms) or guess responses (1059 ms). Dewhurst et al. reasoned that these RTs reflect genuine differences in the speed of the recognition decision that is not influenced by the requirement to make a remember-know distinction. They concluded that the faster RTs for remember responses reflect the greater ease in making recognition decisions that are supported by the recollection of contextual information. Thus, in their view, recollection need not be a slow and effortful process but "can occur rapidly and automatically" (Dewhurst et al., 2006: 158).

### 2.24.2.7 Judgments of Event Frequency

It has been previously noted that different tasks, such as source or plurality judgments, have been used to examine memory for specific details of the prior presentation of events. Another illuminating task concerns memory for frequency, or the number of separate occurrences of an event. Memory for frequency has been studied, in part, to try to determine how multiple occurrences of the event are encoded and represented in memory (for reviews see Howell, 1973; Hintzman, 1976, 1988). Our ability to remember the frequency of events is surprisingly accurate, even in the absence of any intention to do so, and it has been suggested that the encoding of frequency information represents an automatic process (Hasher and Zacks, 1979, 1984).

Logically, estimates of the frequency of prior events could be made in several different ways. Participants might, when asked, try to recollect and count each individual occurrence of an event. Or, participants could estimate the number of occurrences based on the cumulative strength or familiarity that is associated with the event. In either case, participants could also adjust or extrapolate their counts or derived estimates to compensate for failures of encoding or retrieval. These different possibilities form part of the multiple-strategy perspective of frequency estimation developed by Brown (1995, 1997, 2002). This framework provides an excellent example of the flexible manner in which we can interrogate and use our memory. Brown's basic distinction between enumeration-based and nonenumeration-based strategies of frequency estimation also provides a compelling example of a dual-process type of account of memory decisions.

Brown (1995) examined frequency judgments for words presented in either a variable or a consistent context. In each condition participants studied a list of pairs, each consisting of a category label and an exemplar. Different category labels were presented different numbers of times in the list, varying from 0 to 16. In the variable-context condition a different exemplar was presented with each category label (e.g., MAMMAL – dog, MAMMAL – tiger, MAMMAL – horse), whereas in the consistent-context condition the exemplar was always the same (e.g., CITY – London, CITY – London, CITY – London). At test, participants estimated the frequency of the different categories.

A major finding that indicated that subjects used an enumeration or counting strategy in the variable-context condition and a nonnumeration strategy in the consistent-context condition was the changes in the mean RTs of the frequency judgments. The mean frequency estimates and the mean RTs as a function of presentation frequency are shown in **Figure 6**. Mean RT increased sharply as a function of presentation frequency in the variable condition, consistent

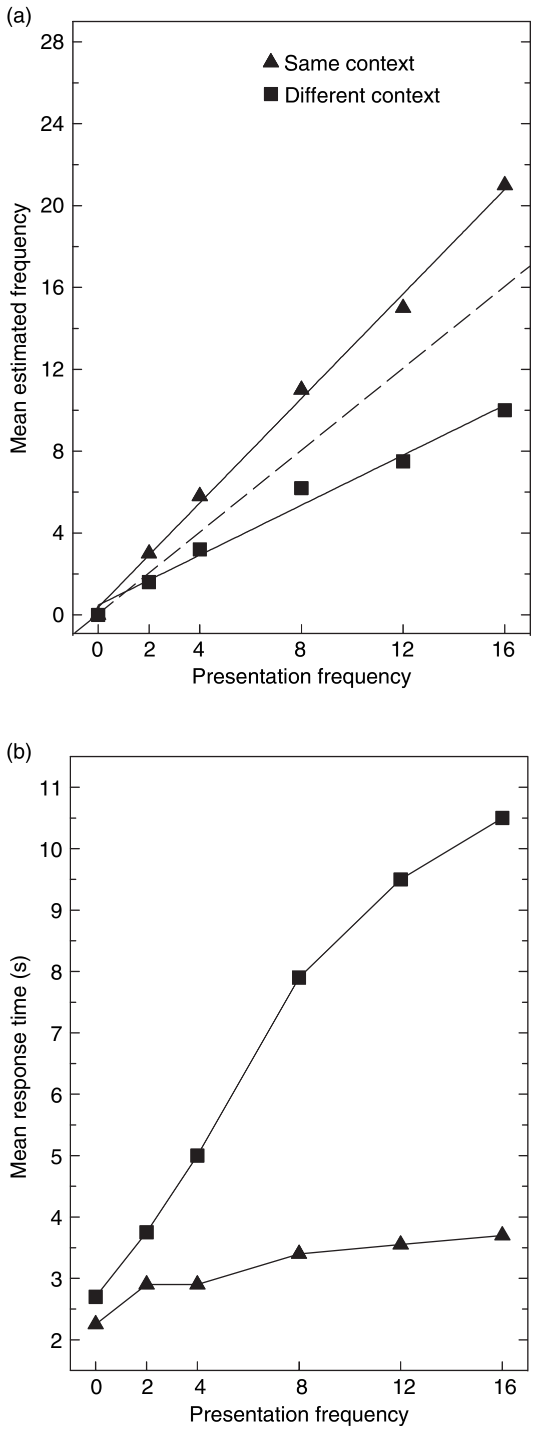


**Figure 6** The figure shows the mean frequency estimates (a) and the mean response times (b) for the different-context and same-context conditions from Brown NR (1995) Estimation strategies and the judgment of event frequency. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 1539–1553; used with permission. In (a), the solid lines represent the best linear fit to the means, and the dashed line represents the actual presentation frequency.

with participants' retrieving and counting the different presentations of the target categories. The different contexts in this condition would support the search and retrieval of the individual occurrences of the categories. In contrast, the increase in mean RT with presentation frequency was far more modest in the same-condition context, indicative of participants' using a more global or inferential estimation strategy that did not involve searching and retrieving memories of the individual presentations.

Three additional findings supported the use of different estimation strategies in the same- and different-context conditions. Participants in the variable-context condition tended to underestimate actual frequency (consistent with failing to retrieve all instances of each event), while participants in the same-context condition tended to overestimate frequency (consistent with a strength-based estimation strategy). Moreover, information about the frequency range influenced the magnitude of participants' estimates in the same- but not in the variable-context condition. Finally, the participants' own verbal protocols indicated their use of the two different strategies.

The evidence indicates that there are two different bases for item recognition decisions and judgments of event frequency – a form of general or global familiarity and recall or recollection. In the next section we consider two tasks that involve memory for associations, or information that represents the relations between items. Each task is believed to involve a recall process, and each task is supported by retrieval cues presented at the time of test.

## 2.24.3 Associative Recognition and Cued Recall

### 2.24.3.1 Associative Recognition

In the standard associative recognition paradigm, participants study random pairs of items and then, at test, try to discriminate between intact or studied pairs and new pairings of rearranged study items. This procedure provides a relatively pure test of memory for the associations between unrelated items formed at study, because both intact and rearranged pairs consist of two old items that individually would be similar in their degree of familiarity. Since this task requires memory for specific associations formed at study, it is usually assumed that recall or recollection plays a dominant role in associative recognition decisions (e.g., Yonelinas, 1997; Hockley and Consoli, 1999; Cameron and Hockley, 2000; Rotello and Heit, 2000; Verde and Rotello, 2004).

Gronlund and Ratcliff (1989) compared the time course of the availability of item and associative information using the response-signal SAT procedure following the study of random word pairs. The response signal functions they obtained in their second experiment are shown in **Figure 7**.

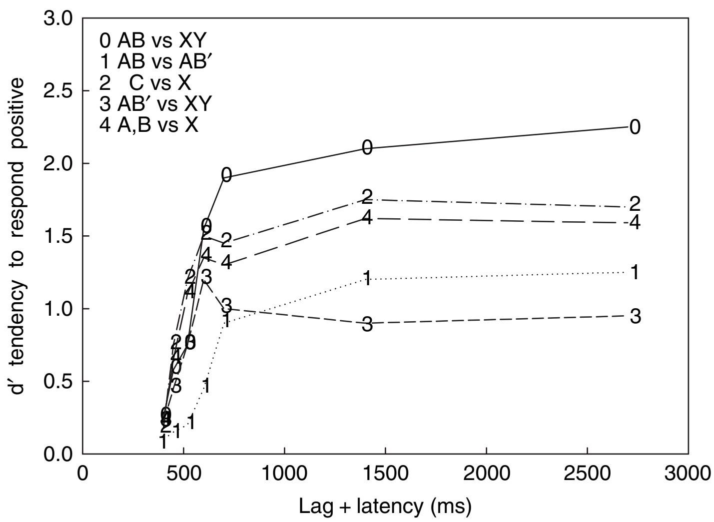


**Figure 7** This figure shows averaged response signal functions from Gronlund SD and Ratcliff R (1989) Time course of item and associative information: Implications for global memory models. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 846–858; used with permission. (The d' tendency to respond positively is given as a function of the total processing time [lag + latency]. Function 0 is AB vs. XY; Function 1 is AB vs. AB′; Function 2 is C vs. X; Function 3 is AB′ vs. XY; and Function 4 is A,B vs. X.)

These functions represent the different types of discriminations that the participants were asked to make. Discriminating between two studied old words versus two new words is shown by Function 0, between intact studied pairs versus rearranged pairs by Function 1, between studied old single words versus new words by Function 2, between rearranged pairs versus pairs of new words by Function 3, and between old words studied in pairs versus new words by Function 4. Functions 0, 2, 3, and 4 represent discriminations that can all be based on item information, or memory for the individual words from the study list. These functions all show similar initial increases in accuracy with response time.

In contrast, the discrimination of intact versus rearranged pairs represented by Function 1 requires memory for the associations made at study. The familiarity of the individual items cannot aid in this discrimination. This function remains at chance at the earliest test lags, and discrimination is delayed relative to the other functions. Gronlund and Ratcliff (1989) also showed that these results are not due to the requirement that participants must read both words of the test pair to discriminate intact from rearranged pairs. Similar results were obtained when the first word of each test pair was presented 200 ms before the second word, and the response signal was measured from the onset of the second word.

Gronlund and Ratcliff (1989) considered two possibilities to explain why the availability of associative information is delayed relative to the availability of item information. One was that for associative recognition a compound cue must first be created. This cue would provide the means to derive a joint match of the two words to memory. Such a matching operation would provide a familiarity value in the same manner as is generally assumed for item recognition. The second possibility was that, whereas item recognition is based on familiarity, associative recognition is based on a slower recall process. In the second view, associative recognition would be similar in nature to cued recall.

### 2.24.3.2 Cued Recall

In the typical episodic memory cued-recall task, participants study random pairs of items, and at test, one item of each pair is presented as a cue to recall the associated member of the pair. We can also consider questions that require participants to retrieve a specific label, name, or fact in a cued-recall test of semantic memory.

In self-paced recall tasks the typical finding is that average error latency is longer than the latency of correct responses, and these two variables are interpreted differently. Correct latency is taken to be a measure of the amount of information about the item that is available in memory. Error latency, on the other hand, is interpreted as an index of the rememberer's willingness to continue searching memory for the item (e.g., Millward, 1964; MacLeod and Nelson, 1984).

In the cued-recall experiments carried out by MacLeod and Nelson (1984), participants studied number-noun pairs (e.g., 48-dollar) or noun-noun pairs (e.g, forest-elbow) and at test tried to recall the second item given the first item of the pair as a retrieval cue. Participants responded aloud, and a voice key was used to measure response time. The instructions emphasized accuracy with no mention that response time was being measured. Participants could take as much time as they needed, but they had to make a response on every trial even if it was a guess. Across their experiments MacLeod and Nelson manipulated retention interval (1, 3, or 5 weeks), levels of processing at study (classifying the nouns in terms of physical size or number of syllables), and study versus test trial repetitions. All of these manipulations had large and reliable effects on accuracy. For example, in Experiment 1 the mean probability of an error increased with retention interval: 0.54 (1 week), 0.75 (3 weeks), and 0.79 (5 weeks). The corresponding mean latencies (in seconds) for correct responses were 3.78, 6.90, and 7.11, and for incorrect responses were 18.12, 17.91, and 14.97. The results suggest a positive correlation between accuracy and correct RT, but the increase in mean RT was not statistically reliable (similar patterns and statistical outcomes were observed in all of the experiments). The results are, though, very clear in showing that mean RTs for incorrect responses do not vary with the manipulations that affected accuracy and are very much slower than correct responses, consistent with the view that correct and incorrect RTs are measuring different processes.

There is considerable evidence to support the conclusion that the latencies of errors are a measure of the rememberer's willingness to continue searching memory in the belief that the additional effort might prove successful. Thompson (1977, as described by MacLeod and Nelson, 1984) measured response times to respond to general-information questions. Then she asked her participants to make feeling-of-knowing judgments in terms of the likelihood of recognizing the correct answer for the questions that they could not recall. Finally, she gave participants a forced-choice recognition test for the nonrecalled answers. The initial error latencies were reliably correlated with the feeling-of-knowing judgments, but not with the final recognition performance. Error latency thus appears to reflect what the rememberer believes to be in memory whether or not the belief is true.

Costerman et al. (1992) and Nelson et al. (1984) have also shown that retrieval latencies are longer for nonrecalled targets that are given higher feeling-of-knowing ratings. Participants will also spend more time attempting to retrieve the correct answer when they are in a ‘tip-of-the-tongue’ state (when they have a strong feeling that a particular answer is in memory and can be retrieved) compared to retrieval failures not accompanied by such a feeling (Schwartz, 2001). Finally, people will also spend longer searching memory and make more correct responses when the rewards for correct responses are high and the penalties for slowness are low, and will spend less time at retrieving with a resultant lower success rate when the penalties for slowness are high and the rewards for correct responses are lower (Barnes et al., 1999).

We have separately considered associative recognition and cued recall. Nobel and Shiffrin (2001) compared the retrieval dynamics of these two tasks with item recognition in order to determine the similarities and differences in the retrieval processes that are involved in each task.

### 2.24.3.3 A Comparison of Item versus Associative Recognition and Cued Recall

Nobel and Shiffrin (2001) used a voice key to measure RT for item recognition and cued recall following study lists of random word pairs. They found that both correct responses (hits vs. correct recalls) and incorrect responses (false alarms vs. intrusions) were much slower for cued recall compared to item recognition. These differences are clearly captured in the plots of the RT distributions fitted by the ex-Gaussian distribution and shown in **Figure 8**. The RT distributions for cued recall and item recognition are markedly different; the cued-recall distributions are shifted to the right, with a greater positive skewness and higher variance.

Nobel and Shiffrin also compared the retrieval dynamics of discrimination for item recognition (old vs. new single items), associative recognition (intact vs. rearranged study pairs), and paired recognition (intact pairs vs. pairs of new words) with cued recall using the response-signal SAT procedure. Their SAT functions for the three recognition tasks

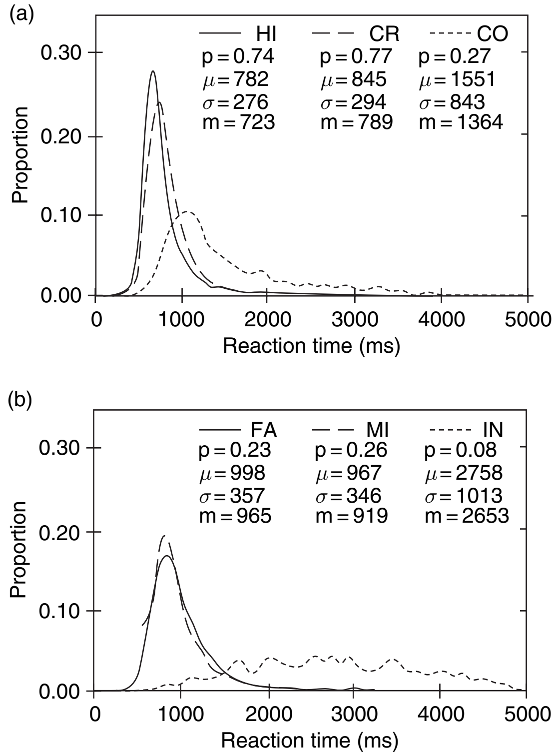


**Figure 8** This figure shows the response time distributions for correct responses: (a) item recognition hits (HI) and correct rejections (CR), and correct cued recalls (CO), and for incorrect responses: (b) item recognition false alarms (FA) and misses (MI), and recall intrusions (IN). Observed by Nobel PA and Shiffrin RM (2001) Retrieval Processes in recognition and cued recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 384–413; used with permission. The proportion of each type of response (p), mean RT ($\mu$), standard deviation ($\sigma$), and median RT (m) are shown in each panel.

are shown in the top portion of **Figure 9**, and the function for cued recall is shown in the bottom portion. These results show that, compared with item and paired recognition, the retrieval dynamics of associative recognition and cued recall are much slower. Moreover, the retrieval dynamics of associative recognition were statistically consistent with those of cued recall.

Based on their different temporal properties, Nobel and Shiffrin proposed that different retrieval processes give rise to associative and cued-recall performance on the one hand, and single-item and paired recognition on the other. In their view, item and paired recognition are based on a familiarity process that involves parallel access to recent episodic representations and leads to relatively fast ‘old’ or ‘new’ responses. In contrast, they argued that cued recall and associative recognition are carried out

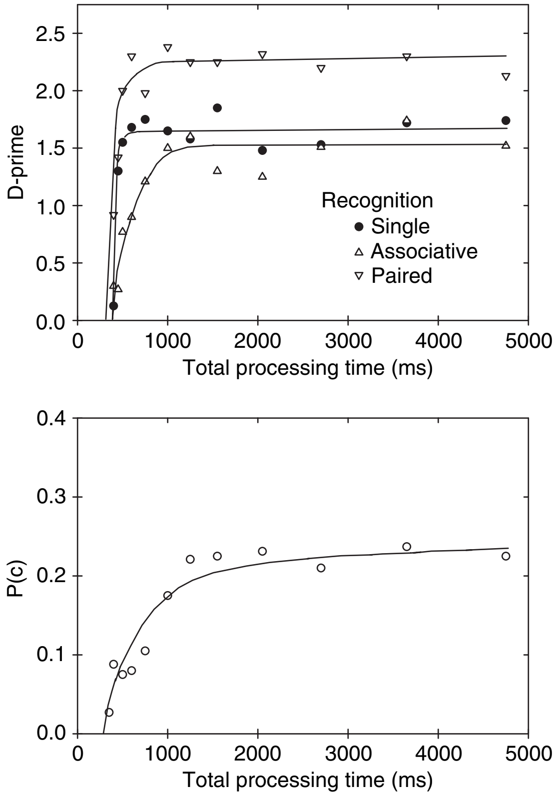


**Figure 9** These functions show signal-to-response accuracy as a function of total processing time for single item, associative, and paired item recognition (top panel), and correct cued recall (bottom panel). The data are from Nobel PA and Shiffrin RM (2001) Retrieval processes in recognition and cued recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 384–413; used with permission.

through a memory search process that involves successive sampling and recovery until the relevant representation of the target is found, or the search is abandoned. Diller et al. (2001) provide a formal description of these processes and fits of this model to their results. The general search process that Nobel and Shiffrin suggested underlies cued recall and associative recognition has also been proposed to account for free recall performance.

## 2.24.4 Recall

### 2.24.4.1 Analyses of Interresponse Times in Free Recall

Free recall requires participants to output as many items from the study list as possible in any order. Thus, it is a sequential task that is spread out over time. While response times in recognition and cued-recall tasks are relatively fast and typically in the order of a few seconds, free recall occurs over many minutes and is characterized by much longer pauses between responses. For this reason an extended sequential search process is assumed in most models of free recall (e.g., Atkinson and Shiffrin, 1968; Shiffrin, 1970; Raaijmakers and Shiffrin, 1980; Metcalfe and Murdock, 1981; Rohrer and Wixted, 1994; Howard and Kahana, 1999).

Although the analysis of the temporal dynamics of free recall has a long history dating back to the seminal work of Bousfield and Sedgewick (1944), measures of response latency in studies of free recall have not been as common as in studies of recognition memory. Indeed, much of the research on free recall has used probability of recall as the dependent measure. This can be problematic, or even misleading, as Roediger and colleagues (e.g; Roediger and Thorpe, 1978; Roediger et al., 1982; see also Wixted and Rohrer, 1994) have pointed out. For example, in a typical free-recall experiment, performance is evaluated after a fixed retrieval period usually lasting only a few minutes. Few studies have examined recall over extended retrieval periods, yet recall can continue to increase even after 20 minutes (e.g., Roediger and Thorpe, 1978).

In the study of free recall, most of the analysis and modeling of response time has been based on interresponse times (IRTs), the time between consecutive retrievals (e.g., Bousfield et al., 1954; Murdock and Okada, 1970; Roediger et al., 1977; Roediger and Thorpe, 1978; Roediger and Tulving, 1979; Raaijmakers and Shiffrin, 1980; Gronlund and Shiffrin, 1986). The basic finding is that IRTs increase in a positively accelerated fashion with output position.

Bousfield and Sedgewick (1944) asked their participants to recall as many different items as possible from specific categories (e.g., quadruped mammals, U.S. cities) for a period of 18 min. Every 2 min the participants were also asked to draw a line under the last recalled item. Bousfield and Sedgewick then plotted the cumulative number of items recalled as a function of time. This analysis revealed that recall slowed continuously; the greatest number of recalled items occurred in the first interval, and fewer numbers of items were recalled in each successive interval. These latency distributions are well described by the cumulative exponential:

$$R(t) = N(1 - e^{-t/\tau})$$

where $R(t)$ equals the total number of items recalled by time $t$, $N$ represents asymptotic recall (r recall after infinite time), and $\tau$ represents the mean latency of the recalled items (Bousfield and Sedgwick, 1944; Indow and Togano, 1970; Roediger et al., 1977). An example of a cumulative recall latency distribution and its best-fitting cumulative exponential distribution is shown in **Figure 10**.

IRTs have also been shown to increase in a positively accelerated fashion with output position, and at any given output position, IRT is a good predictor of the number of items yet to be recalled (Raaijmakers and Shiffrin, 1980). Representative data from Murdock and Okada (1970) are illustrated in **Figure 11**. In this experiment, participants studied lists of 20 common words. Vocal responses were tape-recorded, and IRTs were measured as a function of output position. Each of the different curves in **Figure 11** represents a different total of words recalled that varied from four to nine. Rohrer and Wixted (1994) have shown that the increase in IRTs with output position is found for different list lengths and presentation rates of the study list and is thus a general feature of free recall.

Rohrer and Wixted (1994; see also Wixted and Rohrer, 1994) analyzed the characteristics of IRT distributions by fitting the observed latency distributions with the ex-Gaussian distribution that has been used to describe response time distributions for recognition decisions. **Figure 12** shows the recall latency distributions with the best-fitting ex-Gaussian distributions for different list lengths that varied from three to nine words. Longer study lists resulted in a decrease in the probability of recall and an increase in the latency of recall. The estimates of mu, representing the minimum response times, averaged about 1 s and did not vary significantly with list length. In contrast, the estimates of tau, reflecting the skewness of the distributions, increased reliably from approximately 3 to 7 s across list length. Thus, all of the increase in response time with list length was seen in the exponential component of the ex-Gaussian distribution. Rohrer and Wixted proposed that free recall is based on a relatively brief, normally distributed initiation stage (represented by mu) followed by an exponentially distributed search stage (represented by tau).

Bousfield and Sedgewick (1944) and McGill (1963) noted that the exponential increase of the cumulative latency distributions is consistent with a random search model of memory. In this model, individual items are randomly sampled from a search set, evaluated, and replaced. Thus, early in the process almost every sample from the search set will yield a new item to report. As the random search process continues, however, the probability of retrieving a previously sampled item increases until almost every iteration produces an already sampled item. Retrieval of each new item, therefore, becomes progressively slower. Rohrer and Wixted (1994; Wixted and Rohrer, 1994) also supported this basic account of free recall and considered both serial and

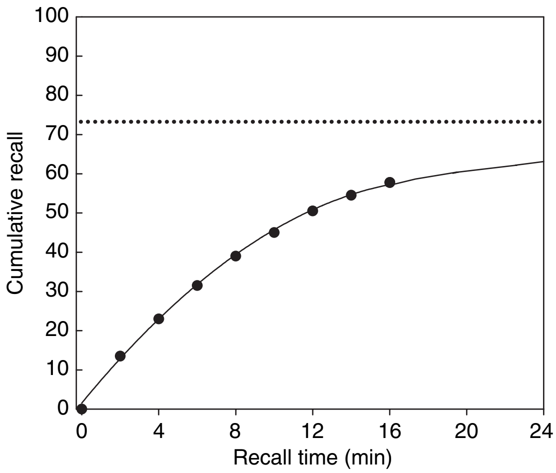


**Figure 10** This figure shows a cumulative free recall latency distribution based on Wixted and Rohrer's (1994) plot of Bousfield and Sedgewick's (1944) results for the cumulative recall of pleasant activities over time. The solid curve represents the best-fitting exponential function and the dotted line indicates the asymptotic level of recall.

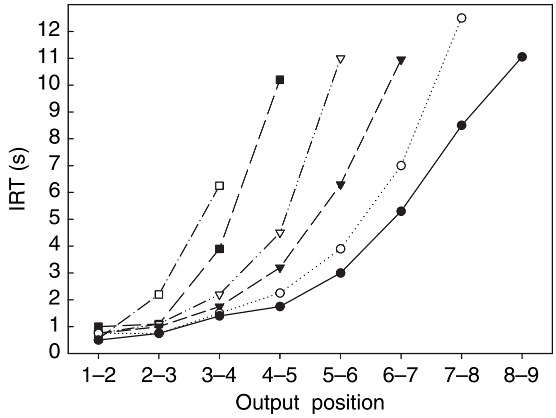


**Figure 11** The increase in interresponse time (IRT) with output position. The six curves represent different total numbers of words recalled varying from four to nine. Data from Murdock BB Jr. and Okada R (1970) Interresponse times in single-trial free recall. *J. Exp. Psychol.* 86: 263–267; used with permission.

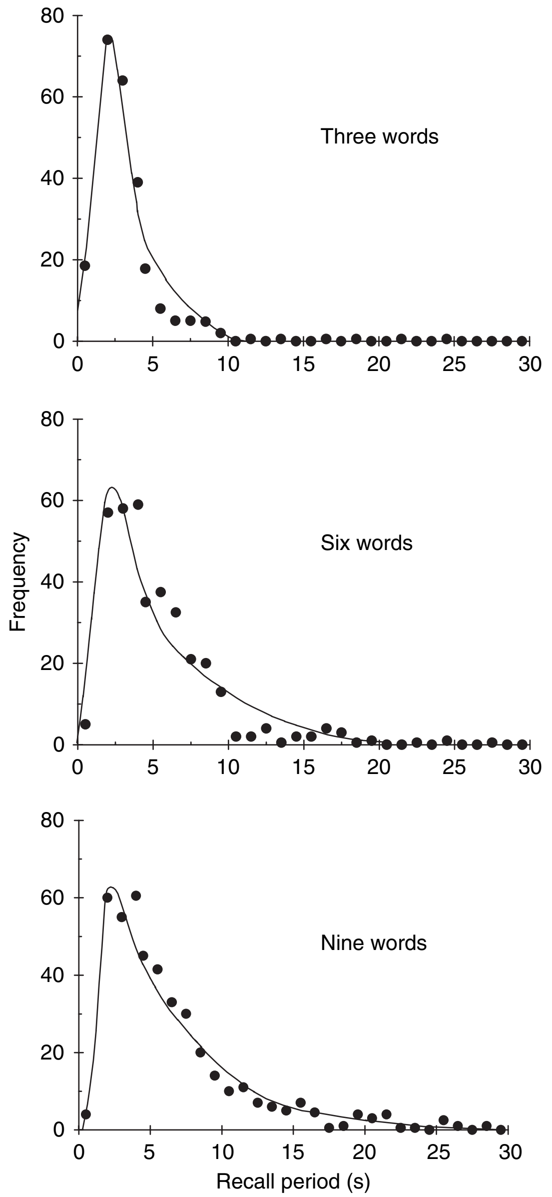


**Figure 12** This figure shows recall latency distributions, grouped into 1-s bins, for three different study list lengths reported by Rohrer D and Wixted JT (1994) An analysis of latency and interresponse time in free recall. *Mem. Cogn.* 22: 511–524; used with permission. The fit of the ex-Gaussian distribution is also shown for each observed distribution.

parallel forms of the search process. They also noted that Raaijmakers and Shiffrin's (1980) search of associative memory model, which was developed as an extension of Shiffrin's (1970) random search model, shares many aspects in common with the random search account.

### 2.24.4.2 The Search of Associative Memory Model

The SAM model (Raaijmakers and Shiffrin, 1980, 1981; Shiffrin and Raaijmakers, 1992) is a sophisticated model of recall that has been successfully applied to a number of different phenomena. Although SAM has given way to the REM model (Shiffrin and Steyvers, 1997), the extension of REM to free recall is borrowed from SAM (Shiffrin, 2003). Very briefly, it is assumed in SAM that memories are represented as 'images' that vary in terms of their associative strengths to each other and the retrieval cue. The retrieval cue serves to activate the search set. In free recall the retrieval cue is the context of the study list. Retrieval consists of repeated sampling of the search set, and the retrieval probability of each item is a function of its associative strength. When an item is retrieved and output, it serves as the retrieval cue for the next sampling. This process continues until a stop rule is invoked based on the elapsed time without a successful retrieval. As Wixted and Rohrer (1994) note, if all images in the search set were activated to the same degree by the retrieval cue, and this remained the case during the entire recall period, then the search process would be equivalent to the random-search-with-replacement model.

A central notion in SAM is that items are associated to varying degrees. Kahana (1996) provided evidence for such associations between items presented sequentially in tests of free recall. Kahana reanalyzed data from a number of free recall studies in terms of the probability of recalling a given item as a function of its distance in the study list from the last item recalled (the conditional response probability). An example of such a function is shown in the left panel of **Figure 13**. Two aspects of these results are notable and are consistent across studies. Kahana termed these aspects of the results contiguity and asymmetry. Contiguity refers to the fact that items tend to be recalled after items that were studied in adjacent list positions. That is, item 8 is more likely to be recalled after item 7 is recalled than after item 5. Asymmetry refers to the finding that for items that were adjacent to each other in the study list and that were recalled after each other, forward transitions (recall item 7 then recall item 8) are about twice as likely as backward transitions (recall item 8 then item 7).

Kahana also examined conditional response latency functions, where IRTs between successively recalled items are plotted as a function of their

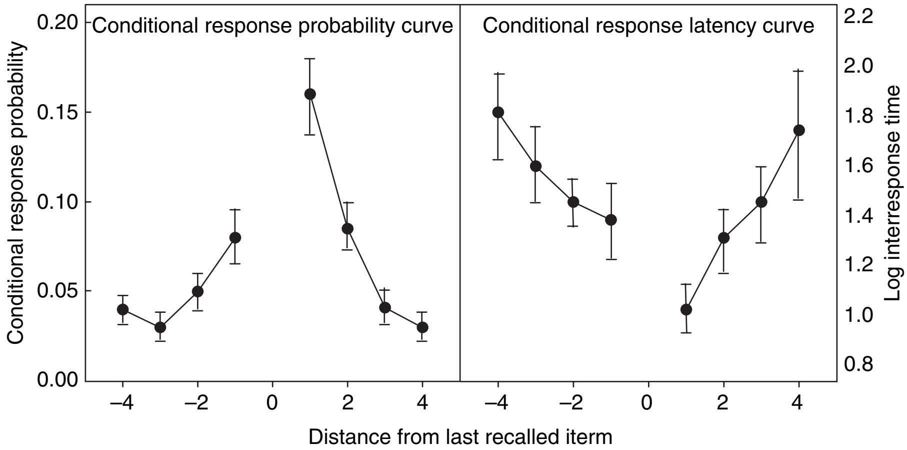


**Figure 13** The conditional response probability (left panel) and conditional response latency (right panel) curves reported by Kahana MJ (1996) Associative retrieval processes in free recall. *Mem. Cogn.* 24: 103–109, based on Murdock and Okada's (1970) free recall results; used with permission. (The error bars reflect 95% confidence intervals for each mean.)

proximity in the study list. These IRTs are shown in the right panel of **Figure 13**, and it is clear that the IRT functions mimic the conditional response probability functions – mean IRT increases as the distance between the items' positions in the study list increases. These results indicate that participants studying random lists of words tend to associate the list items in a pair-wise fashion, and the conditional response probability and conditional response latency functions reflect the strength of these associations, as SAM would predict.

### 2.24.4.3 The Search Set

A critical aspect of any version of the random search-with-replacement model is defining the search set. In the SAM model it is assumed that the retrieval cue serves to activate the search set. Research has shown that certain types of retrieval cues are able to delineate or reduce the search set, whereas others do not.

In categorized free-recall tasks, participants study random lists of words drawn from different semantic categories such as precious stones and occupations and, at test, recall the semantically related items together (i.e., semantic clustering; Bousfield, 1953). Within-category IRTs increase with output position, and IRTs are longer when recall changes from one category to another (Pollio, 1964; Patterson et al., 1971; Graesser and Mandler, 1978; Wingfield et al., 1998). The pattern of IRTs is consistent with a random search and replacement model that operates at the level of the individual categories and with the SAM model given the assumption that the association between items is greater for within-category than between-category items.

Wixted and Rohrer (1994) discuss two studies of semantic memory that illustrate how some retrieval cues can serve to narrow the search set, while other types of cues cannot. Herrmann and Murray (1979) asked participants to recall items from large categories such as bodies of water, and smaller, nested categories such as lakes. Metlay et al. (1971) asked participants to recall items from different categories (e.g., names of U.S. presidents) that could be further subdivided (e.g., presidents' names that contain the letter *y*, n = 5, or the letter *s*, n = 11). Analyses of the cumulative latency functions indicated that participants could search lakes separately from the larger category of bodies of water, but could not restrict their search for presidents based on letters in their names. Presumably, lakes are stored as a separate category in semantic memory, and people can use this information to reduce the search set. Presidents' names, however, are not stored by their component letters, and the participants thus had to generate the entire set of 32 names and only report those names that conformed to the letter cue.

Roediger and Tulving (1979) provide two episodic memory examples of the failure of retrieval cues to restrict the search set. They presented participants with lists of 64 words in which there were eight words from eight different common semantic categories (e.g., vegetables). In addition, the words in each category began with the same set of eight letters. Participants were informed about the categorical nature of the lists, and the list was presented blocked by category, with the category name presented before the category exemplars. The participants were not informed of the initial letters of the words in each category. There were three groups of subjects. A control group was instructed to recall all items from all categories. A second group was given four letters on their recall sheets and instructed to recall only the words that did not begin with those letters. The third group was given four category names and were told not to recall items from these categories, but only recall items from the other four categories which were not named. As one would expect based on the results of Metlay et al. (1971), participants could not restrict their search based on letter cues. Surprisingly, and in contrast to the results of Herrmann and Murray's (1979) nested category-cued experiment, participants could also not restrict their search based on the category cues. The mean cumulative recall functions for the critical words were the same in all three groups of Roediger and Tulving's experiment. It is not at all clear why participants would apparently 'waste time' in retrieving an excluded category or continue to search a category after retrieving and rejecting one exemplar from an excluded category.

### 2.24.4.4 Serial Recall

Serial recall requires participants to report list items in the order of their presentation. The emphasis on order information in this task has led to a focus on transposition errors that occur when an item is recalled in an incorrect list position. Transposition errors are categorized as anticipation errors when an item is recalled in an earlier serial position, and postponement errors when an item is recalled in a later list position.

Transposition errors can be measured in terms of the numeric difference between an item's study position and recalled position. Thus, an item recalled in its correct position would have a transposition value of zero. Anticipation errors have a negative transposition value, and postponement errors have a positive value. Transposition gradients can be measured by plotting the proportion of recalled items as a function of the transposition value. As summarized by Farrell and Lewandowsky (2004), these gradients reveal three regularities of serial recall. First, the gradients peak at a value of zero because most items are recalled in their correct position. Second, the probability of errors declines as the absolute transposition value increases; most errors occur near their correct position. Finally, the transposition gradients tend to be symmetrical. That is, the anticipation and postponement error gradients mirror each other.

In contrast to the long history of measuring response time in free recall, latency has only recently been used as a dependent measure of serial recall performance. Investigators have examined total output times (Dosher and Ma, 1998; Hulme et al., 1999) and correct IRTs for each serial position (e.g., Anderson and Matessa, 1997; Anderson et al., 1998; Cowan et al., 1998; Kahana and Jacobs, 2000; Mayberry et al., 2002; Oberauer, 2003; Farrell and Lewandowsky, 2004). In forward serial recall for subspan list lengths, mean IRTs typically show longer output times for recall of the first item and a relatively flat latency serial position curve for recall of the subsequent items. The delay in recalling the first item may reflect an initial preparatory stage (Farrell and Lewandowsky, 2004). Thus, when cumulative latency is plotted as a function of serial position, the increase in time is approximately linear (e.g., Dosher, 1999). Representative error transposition gradients and serial position curves for accuracy, latency, and cumulative latency reported by Farrell and Lewandowsky (2004) are shown in **Figure 14**.

IRT serial position functions for list lengths that exceed memory span also show the longer output time for the first item, but the remainder of the curve appears to show a more inverted-U shape with faster IRTs at the beginning and end of the list. **Figure 15** shows such functions obtained by Kahana and Jacobs (2000). In this experiment, participants learned lists of 11, 12, and 13 items over 12 experimental sessions. The latency serial position functions are similar for each list length and degree of learning (the first two sessions vs. the last six sessions of the experiment). For middle serial positions, IRTs vary in a nonmonotonic fashion, indicating consistencies in the participants' temporal groupings of the items. The averaged IRT functions, however, obscure individual variability of the groupings. Kahana and Jacobs examined these functions for each participant and reported that the individual IRT functions show that some participants grouped the lists in a consistent manner with longer IRTs for every second, third, or fourth item in the list. The IRT functions for other participants did not show such pronounced patterns, but still showed strong tendencies for longer IRTs in the middle and shorter IRTs at the beginning and end of the lists. Kahana and Jacobs suggested that these patterns reflect the participants' grouping of items into different-sized

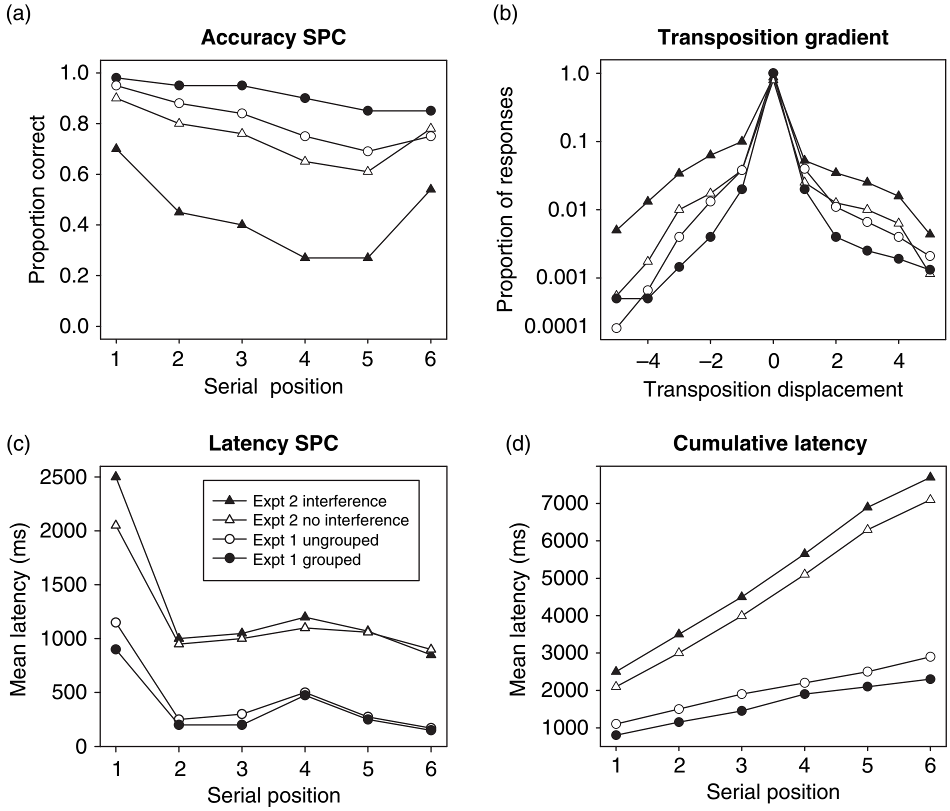


**Figure 14** This figure shows the serial position curves (SPC) for (a) accuracy, (b) transposition error gradients, (c) latency serial position curves, and (d) cumulative latency serial position curves for Experiments 1 and 2 of the study of serial order recall from Farrell S and Lewandowsky S (2004) Modelling transposition latencies: Constraints for theories of serial order memory. *J. Mem. Lang.* 51: 115–135; used with permission.

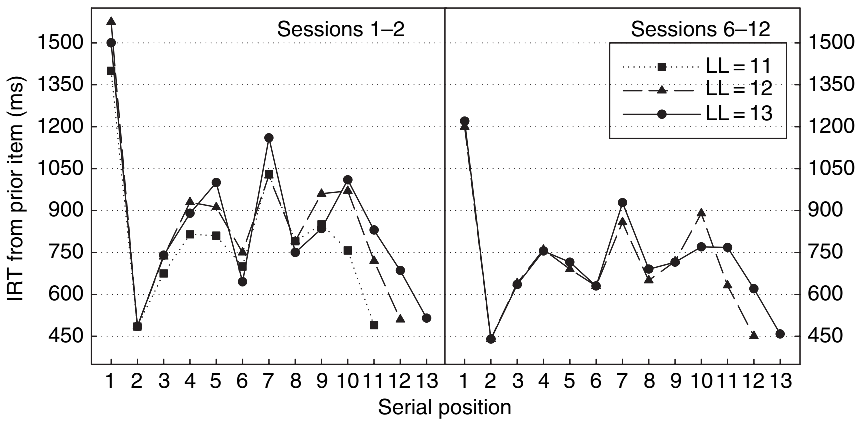


**Figure 15** Average interresponse times (IRT) as a function of serial position for all perfect trials for each list length. From Kahana MJ and Jacobs J (2000) Interrersponse times in serial recall: Effects of intraserial repetition. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1188–1197; used with permission. The left panel shows data from the lists from sessions 1–2, and the right panel shows the results for sessions 6–12.

chunks such that IRTs are longer for the first item of a group than the items within a group.

## 2.24.5 Conclusions and Controversies

### 2.24.5.1 Matching versus Searching

It is quite clear that there are both qualitative and quantitative differences between the temporal dynamics of item recognition on the one hand, and associative recognition, cued recall, free recall, and serial recall on the other. Item recognition responses are generally quite fast for both correct old and new decisions. In contrast, RT is much slower in associative recognition and recall-based tasks, and the latencies of correct and incorrect recall responses are measures of different processes.

It seems reasonable to conclude, therefore, as did Nobel and Shiffrin (2001), that item recognition is generally based on a strength-of-evidence variable, or familiarity, that is derived from a relatively fast matching process that is carried out in parallel, whereas associate recognition and recall are based on slower, sequential, search-based processes. Such a conclusion must be correct in the broader sense. Familiarity alone would usually provide a sufficient basis for item recognition decisions, but would not suffice for associative recognition or recall where more specific information must be retrieved. Such a sweeping conclusion, however, glosses over a number of important questions and details that remain to be resolved. This chapter concludes with brief considerations of some of these controversies.

### 2.24.5.2 Familiarity versus Recollection in Item Recognition

Most, if not all, researchers agree that recollection can play a role in recognition decisions, and most global matching models of recognition memory allow for decisions to be based on either matching strength or on recollection of details (see Hintzman and Curran, 1994, for a discussion of this point). The controversial question is whether recognition is largely based on familiarity, as single-process theorists advocate, or routinely involves recollection, as dual-process theorists have argued.

An argument in favor of the single-process view is that recognition decisions are typically much faster than decisions involving recall. If recollection involves a slower search process, it cannot be a general feature of recognition decisions. Nobel and Shiffrin (2001), however, point out that response latency would not be sufficient to distinguish between single-process and dual-process views of recognition if it were assumed that recollection involves a fast, truncated search process. An example of such a truncated search process would be stopping after the retrieval of the first sample in a successive sampling and recovery search process. Nobel and Shiffrin also noted that it might be almost impossible to distinguish between single- and dual-process views of recognition if there is a strong correlation between familiarity and the probability of retrieval success of such a truncated search process.

The notion of a truncated search process underlying recollection also provides an answer to the question of whether recollection-based recognition decisions are slow relative to familiarity-based decisions (e.g., Yonelinas, 2002) or the reverse (e.g., Dewhurst, et al., 2006). Recognition decisions that are based on any retrieved detail of the prior experience, and that participants characterize as a ‘remember’ rather than a ‘know’ old response, could be associated with very fast RTs, as Dewhurst et al. (2006) have proposed, when retrieval is based on a truncated search process. In contrast, recognition decisions that must be based on the retrieval of a specific detail or details of the prior episode, such as source discriminations or discriminations between targets and highly similar lures (e.g., ‘frog’ vs. ‘frogs’; Hintzman and Curran, 1994), would be much slower decisions, because the search process could not be truncated or abbreviated. Thus, recollection might be fast or slow, depending on the task requirements.

### 2.24.5.3 Defining the Search Set

In models of recognition memory the search set is often defined in functional terms. For example, Ratcliff (1978) used a resonance metaphor to describe the memory set. In this metaphor, the test probe and item representations in memory are seen as tuning forks. The tuning fork representing the probe rings and evokes sympathetic vibrations from all items in memory that have tuning forks with similar frequencies. Thus the search set is defined by the degree to which items in memory are similar to the test probe. Search sets are also defined by degree of activation or match in several global matching models such as MINERVA 2 (Hintzman, 1988), SAM (Gillund and Shiffrin, 1984), and REM (Shiffrin and Steyvers, 1997). In distributed global matching models such as TODAM (theory of distributed associative memory; Murdock, 1982) and CHARM (composite holographic associative recall model; Metcalfe, 1982), the functional memory set is the entire memory representational system. In all of these models the size of the search set is not a critical issue, because the potentially large number of items in the search set that are not highly activated, or are very dissimilar to the probe, do not greatly influence the decision system and thus do not affect performance.

The size of the functional search set may also not be a problem for dual-process models of recognition that assume that recollection is based on a truncated search process, and for models of associative recognition and cued recall. In these cases, the search process may be very focused because of the retrieval cues that are present at test.

The size of the search set is, though, a critical aspect of any version of the random search-with-replacement model of recall. In the SAM model it is assumed that retrieval cues serve to activate the relevant search set. These retrieval cues are the context and successively retrieved items, and they will activate images in memory that are associated with them. Thus, the functional search set comprises the memory images that have an association with a given set of cues. SAM has been successively applied to a broad range of recall phenomena, but its applications have largely been restricted to recall of a given list based on the associations formed between the list items. Thus the functional search set for most of the simulations of SAM has been restricted to the study list.

Sirotin et al. (2005) present an extension of the SAM model (eSAM) that adds a semantic memory store, a contextual drift mechanism, and a memory search mechanism that uses both episodic and semantic associations. These researchers show that eSAM is capable of simulating the effects of both preexperimental semantic knowledge and prior episodic information in an episodic free-recall task. These additions mean that the functional search set in eSAM is thus potentially very large. This model has not been extended to fitting IRTs, and the temporal characteristics of many of the effects that the model has been applied to have not been evaluated. Thus, the implications of the assumptions of this extended search model for the temporal dynamics of free recall are not known.

As previously discussed, research has shown that certain types of retrieval cues are able to delineate or reduce the search set, whereas others do not. For example, cues defining a semantic category are effective cues in recall from semantic memory (e.g., Hermann and Murray, 1979) and give rise to semantic clustering in recall of categorized lists (e.g., Graesser and Mandler, 1978). While participants can use such relevant cues to guide search and retrieval, it is not clear why the participants in Roediger and Tulving's (1979) episodic memory study could not use similar types of cues to omit categories and exemplars from the search process.

### 2.24.5.4 Contradiction and Knowing Not

A problem conceptually related to the issue of defining the relevant search set is the question of how we know what we do not know, or what Kolers and Palef (1976) termed 'knowing not.' Most models of recognition memory, such as Sternberg's serial search model of short-term memory, Ratcliff's diffusion model, and the family of global matching models, treat a negative response as a default decision that is reached when there is insufficient evidence to support a positive decision. In this view, the latency of correct rejections cannot take less time than the slowest positive responses. This has been shown to be generally the case in standard recognition studies involving lists of unrelated words.

Mewhort and Johns (2000; Johns and Mewhort, 2002, 2003) have challenged this view with their demonstration that participants were fastest to correctly reject negative probes when they did not share a feature with the study set (the extralist feature effect). Mewhort and Johns argued that negative decisions are not a default decision, but rather, are based on an assessment of contradictory evidence. Kolers and Palef (1976) also challenged the default interpretation of negative responses based on their demonstration that participants can make faster negative than positive responses when deciding whether or not they had visited different cities. Shanon (1974, as cited in Kolers and Palef, 1976) found that the latency of negative responses was faster when the participant also had not visited the country in which the city is located. That is, participants were faster to say that they had never visited Paris if they had also never been to France. Kolers and Palef took this as evidence that participants might have used a hierarchical search strategy. With such a strategy one might be able to quickly respond that they have not been to Paris if they have not been to Europe or have not been to France, but their response time would become progressively slower the more specific or fine grained the search set must become. To borrow Mewhort and Johns' concept of contradiction, participants are faster to reject an item when the features of the probe (have you been to Toronto) contradict a large search set (North America) than progressively smaller search sets (Canada and Ontario). Thus, knowing not may involve the use of contradiction or be another manifestation of the extralist feature effect. Both effects may require that the appropriate search set be distinct or well defined, and that the relevant feature dimension or dimensions be highly salient.

### 2.24.5.5 Temporal Dynamics and Models of Memory

The analysis of RT provided the initial basis for search models of free recall and has provided a means to test and compare models of recognition and cued recall and, more recently, serial recall. Nevertheless, models of memory have not, for the most part, been directly concerned with accounting for RT. Gronlund and Ractliff (1989) pointed out that a general problem of the first generation of global matching models of item recognition was that they were essentially static and thus did not have mechanisms that are able to naturally predict the temporal dynamics of the search, retrieval, and decision processes. Diller et al. (2001) essentially echoed this comment when they noted that

> . . . although the use of single-step retrieval for recognition and sequential search for cued recall has rather obvious implications for RT predictions, the SAM and REM models have been restricted for the most part to accuracy predictions. (Diller et al., 2001: 414).

In a similar vein, Farrell and Lewandowsky (2004) commented that models of serial recall have neglected recall times because they have historically been concerned with measures of accuracy.

Gronlund and Ratcliff went further to suggest that temporal retrieval dynamics "provide a set of phenomena with which the next generation of theories must deal" (Gronlund and Ractliff, 1989: 857). This prediction has not been fulfilled because, I believe, we still do not fully understand the relationship between accuracy and RT. As we have seen, it is typically the case that accuracy and latency covary. That is, a number of variables such as confidence, list length, presentation rate, number of presentations, test, and study position influence accuracy and RT in complementary ways. It is therefore tempting to conclude that these two dependent variables are "two sides of the same coin" (to coin the phrase used by Kahana and Loftus, 1999). But there are also examples in which accuracy and RT are not highly correlated and therefore provide different measures of performance (e.g., MacLeod and Nelson, 1984; Rohrer and Wixted, 1994; Nobel and Shiffrin, 2001). As Kahana and Loftus (1999) argued, accuracy and RT can only be two sides of the same coin when the cognitive process of interest is a single operation that acts on a single type of information. Clearly, the processes underlying memory search and retrieval are much more complex, and thus accuracy and RT, although often highly correlated, cannot be simply two sides of the same coin.

Because it is not obvious how to marry the processes that produce changes in accuracy with those that give rise to the observed changes in RT, different approaches have been taken to model accuracy and RT. To use models of item recognition as an example, in Ratcliff's (1978) diffusion model the temporal dynamics are a property of the comparison process. In contrast, Hockley and Murdock (1987) proposed a dynamic model of the decision system which evaluates the outcome of the matching process over time to provide a means for Murdock's (1982) distributed associative model of memory, TODAM, to account for RT. Diller et al. (2001) adopted yet another approach in their assessment of retrieval completion (ARC-REM) model that they developed to enable REM to account for RT in recognition and recall. In this model it is assumed that the features of the probe are activated and become part of the comparison process gradually over time. The rememberer, given time, will wait until a sufficiently high proportion of probe features have become active and then interrupt the retrieval process to read out the current odds value and respond accordingly. This model has the ability to dissociate accuracy from RT.

Just as there are different ways to represent information in memory and different ways to search and retrieve this information, there are different ways to represent the temporal dynamics of the search, retrieval, and decision processes. I do not believe we will be able to solve one answer at a time. Rather, we must continue to explore different ways to represent the interplay between the encoding, representation, and retrieval of information on the one hand, and their associated temporal dynamics on the other, in order to eventually understand how they are related to one another.

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## References


Anderson JR, Bothell D, Lebiere C, and Matessa M (1998) An integrated theory of list memory. *J. Mem. Lang.* 38: 341–380.

Anderson JR and Matessa M (1997) A production system theory of serial memory. *Psychol. Rev.* 104: 728–748.

Anderson JR and Milson R (1989) Human memory: An adaptive perspective. *Psychol. Rev.* 96: 703–719.

Ashby FG, Tein JY, and Balakrishman JD (1993) Response time distributions in memory scanning. *J. Math. Psychol.* 37: 526–555.

Atkinson RC, Herrmann DJ, and Westcourt KT (1974) Search processes in recognition memory. In: Solso RL (ed.), *Theories in Cognitive Psychology: The Loyola Symposium*, pp. 101–146. Hillsdale, NJ: Erlbaum.

Atkinson RC and Juola JF (1973) Factors influencing speed and accuracy of word recognition. In: Kornblum S (ed.) *Attention and Performance IV*, pp. 583–612. New York: Academic Press.

Atkinson RC and Juola JF (1974) Search and decision processes in recognition memory. In: Krantz DH, Atkinson RC, Luce RD, and Suppes P (eds.) *Contemporary Developments in Mathematical Psychology,* vol. 1, pp. 243–293. San Francisco: Freeman.

Atkinson RC and Shiffrin RM (1968) Human memory: A proposed system and its control processes. In: Spence KW and Spence JT (eds.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 2, pp. 89–195. New York: Academic Press.

Aube M and Murdock BB Jr. (1974) Sensory stores and high speed scanning. *Mem. Cogn.* 2: 27–33.

Baddeley AD and Ecob R (1973) Reaction time and short-term memory: Implications of repetition effects for the shigh-speed exhaustive scan hypothesis. *Q. J. Exp. Psychol.* 25: 229–240.

Banks WP and Fariello GR (1974) Memory load and latency in recognition of pictures. *Mem. Cogn.* 2: 144–148.

Barnes AE, Nelson TO, Dunlosky J, Mazzoni G, and Narens L (1999) An integrative system of metamemory components involved in retrieval. In: Gopher D and Koriat A (eds.) *Attention and Performance XVII: Cognitive Regulation of Performance: Interaction of Theory and Application*, pp. 287–314. Cambridge, MA: MIT Press.

Boldini A, Russo R, and Avons SE (2004) One process is not enough! A speed-accuracy tradeoff study of recognition memory. *Psychon. Bull. Rev.* 11: 353–361.

Bousfield WA (1953) The occurrence of clustering in the recall of randomly arranged associates. *J. Gen. Psychol.* 49: 229–249.

Bousfield WA and Sedgewick CHW (1944) An analysis of restricted associative responses. *J. Gen. Psychol.* 30: 149–165.

Bousfield WA, Sedgewick CHW, and Cohen BH (1954) Certain temporal characteristics of the recall of verbal associates. *Am. J. Psychol.* 67: 111–118.

Brown NR (1995) Estimation strategies and the judgment of event frequency. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 1539–1553.

Brown NR (1997) Context memory and the selection of fequency estimation strategies. *J. Exp. Psychol. Learn. Mem. Cogn.* 23: 898–914.

Brown NR (2002) Encoding, representing, and estimating event frequencies: A multiple strategy perspective. In: Sedlmeier P and Betsch T (eds.) *Frequency Processing and Cognition*, pp. 37–53. Oxford: Oxford University Press.

Burrows D and Okada R (1971) Serial position effects in high-speed memory search. *Percept. Psychophys.* 10: 305–308.

Burrows D and Okada R (1975) Memory retrieval from short and long lists. *Science* 188: 1031–1033.

Cameron T and Hockley WE (2000) The revelation effect for item and associative recognition: Familiarity versus recollection. *Mem. Cogn.* 28: 176–183.

Corballis MC (1967) Serial order in recognition and recall. *J. Exp. Psychol.* 74: 99–105.

Corballis MC, Kirby J, and Miller A (1972) Access to elements of a memorized list. *J. Exp. Psychol.* 94: 185–190.

Corbett A and Wickelgren WA (1978) Semantic memory retrieval: Analysis by speed-accuracy tradeoff functions. *Q. J. Exp. Psychol.* 30: 1–15.

Costermands J, Lories G, and Ansay C (1992) Confidence level and the feeling of knowing in question answering: The weight of inferential processes. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 142–150.

Cowan N, Wood NL, Wood PK, Keller T, Nugent L, and Keller CV (1998) Two separate verbal processing rates contributing to short-term memory span. *J. Exp. Psychol. Gen.* 127: 141–160.

Craik FIM and Lockhart RS (1972) Levels of processing: A framework for memory research. *J. Verbal Learn. Verbal Behav.* 11: 671–684.

Dennis S and Humphreys MS (2001) A context noise model of episodic word recognition. *Psychol. Rev.* 108: 452–478.

Dewhurst SA and Conway MA (1994) Pictures, images, and recollective experience. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 1088–1098.

Dewhurst SA, Hitch GJ, and Barry C (1998) Separate effects of word frequency and age of acquisition in recognition and recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 24: 284–298.

Dewhurst SA, Holmes SJ, Brandt KR, and Dean GM (2006) Measuring the speed of the conscious components of recognition memory: Remembering is faster than knowing. *Conscious. Cogn.* 15: 147–162.

Diana RA, Reder LM, and Park H (2006) Models of recognition: A review of arguments in favor of a dual-process account. *Psychon. Bull. Rev.* 13: 1–21.

Diller DE, Nobel PA, and Shiffrin RM (2001) An ARC-REM model for accuracy and response time in recognition and recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 414–435.

Donaldson W (1996) The role of decision processes in remembering and knowing. *Mem. Cogn.* 24: 523–533.

Donders FC (1868/1969) Over de snelheid van psychische processen. (On the speed of mental processes.) *Onderzoekingendegaan in het physiologisch Laboratorium der Ugtrechtsche Hoogeschool,* Tweede reeks, 11: 92–130, Koster WG (trans.). In: Koster WG (ed.) Attention and Performance II. *Acta Psychol*. 30: 412–431.

Dosher BA (1981) The effect of delay and interference: A speed accuracy study. *Cogn. Psychol.* 13: 551–582.

Dosher BA (1984) Degree of learning and retrieval speed: Study time and multiple exposures. *J. Exp. Psychol. Learn. Mem. Cogn.* 10: 541–574.

Dosher BA (1999) Item interference and time delays in working memory: Immediate serial recall. *Int. J. Psychol.* 34: 276–284.

Dosher BA and Ma J-J (1998) Output loss or rehearsal loop? Output-time versus pronunciation-time limits in immediate recall for forgetting-matched materials. *J. Exp. Psychol. Learn. Mem. Cogn.* 24: 316–335.

Dosher BA and Rosedale G (1991) Judgments of semantic and episodic relatedness: Common tme-course and failure of segregation. *J. Mem. Lang.* 30: 125–160.

Dunn JC (2004) Remember-know: A matter of confidence. *Psychol. Rev.* 111: 524–542.

Farrell S and Lewandowsky S (2004) Modelling transposition latencies: Constraints for theories of serial order memory. *J. Mem. Lang.* 51: 115–135.

Gardiner JM, Gawlik B, and Richardson-Klavehn A (1994) Maintenance rehearsal affects knowing, not remembering; elaborative rehearsal affects remember, not knowing. *Psychon. Bull. Rev.* 1: 107–110.

Gardiner JM, Ramponi C, and Richardson-Klavehn A (1999) Response deadline and subjective awareness in recognition memory. *Conscious. Cogn.* 8: 484–496.

Gardiner JM and Richardson-Klavehn A (2000) Remembering and knowing. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 229–244. Oxford: Oxford University Press.

Gillund G and Shiffrin RM (1984) A retrieval model for both recognition and recall. *Psychol. Rev.* 91: 1–67.

Glanzer M and Adams JK (1985) The mirror effect in recognition memory. *Mem. Cogn.* 13: 8–20.

Glanzer M and Adams JK (1990) The mirror effect in recognition memory: Data and theory. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 5–16.

Graesser A and Mandler G (1978) Retrieval strategies in recall of natural categories and categorized lists. *J. Exp. Psychol. Hum. Learn. Mem.* 4: 86–100.

Gronlund SD and Ratcliff R (1989) Time course of item and associative information: Implications for global memory models. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 846–858.

Gronlund SD and Shiffrin RM (1986) Retrieval strategies in recall of natural categories and categorized lists. *J. Exp. Psychol.* 12: 550–561.

Hasher L and Zacks RT (1979) Automatic and effortful processes in memory. *J. Exp. Psychol. Gen.* 108: 356–388.

Hasher L and Zacks RT (1984) Automatic processing of fundamental information: The case of frequency of occurrence. *Am. Psychol.* 39: 1372–1388.

Heathcote A, Popiel SJ, and Mewhort DJK (1991) Analysis of response time distributions: An example suing the Stroop task. *Psychol. Bull.* 109: 340–347.

Henson RNA, Rugg MD, Shallice T, Josephs O, and Dolan RJ (1999) Recollection and familiarity in recognition memory: An even-related functional magnetic resonance imaging study. *J. Neurosci.* 19: 3962–3972.

Herrmann DJ and Murray DJ (1979) The role of category size in continuous recall from semantic memory. *J. Gen. Psychol.* 101: 205–218.

Hintzman DL (1976) Repetition and memory. In: Bower GH (ed.) *The Psychology of Learning and Motivation,* vol. 10, pp. 47–91. New York: Academic Press.

Hintzman DL (1988) Judgments of frequency and recognition memory in a multiple-trace memory model. *Psychol. Rev.* 95: 528–551.

Hintzman D and Caulton DA (1997) Recognition memory and modality judgments: A comparison of retrieval dynamics. *J. Mem. Lang.* 37: 1–23.

Hintzman D, Caulton DA, and Levitin DJ (1998) Retrieval dynamics in recognition and list discrimination: Further evidence of separate processes of familiarity and recall. *Mem. Cognit.* 26: 449–462.

Hintzman D and Curran T (1994) Retrieval dynamics of recognition and frequency judgments: Evidence for separate processes of familiarity and recall. *J. Mem. Lang.* 33: 1–18.

Hirshman E and Master S (1997) Modeling the conscious correlates of recognition memory: Reflections on the remember-know paradigm. *Mem. Cogn.* 25: 345–351.

Hockley WE (1984) Analysis of response time distributions in the study of cognitive processes. *J. Exp. Psychol. Learn. Mem. Cogn.* 10: 598–615.

Hockley WE (1994) Reflections of the mirror effect for item and associative recognition. *Mem. Cogn.* 22: 713–722.

Hockley WE and Consoli A (1999) Familiarity and recollection in item and associative recognition. *Mem. Cogn.* 27: 657–664.

Hockley WE and Corballis MC (1982) Tests of serial scanning in item recognition. *Can. J. Psychol.* 36: 189–212.

Hockley WE, Hemsworth DH, and Consoli A (1999) Shades of the mirror effect: Recognition of faces with and without sunglasses. *Mem. Cogn.* 27: 128–138.

Hockley WE and Murdock BB Jr. (1987) A decision model for accuracy and response latency in recognition memory. *Psychol. Rev.* 94: 341–358.

Howard MW and Kahana MJ (1999) Contextual variability and serial position effects in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 923–941.

Howell WC (1973) Representation of frequency in memory. *Psychol. Bull.* 80: 44–53.

Hulme C, Newton P, Cowan N, Stuart G, and Brown G (1999) Think before you speak: Pauses, memory search, and trace redintegration processes in verbal memory span. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 447–463.

Indow T and Togano K (1970) On retrieving sequences from long-term memory. *Psychol. Rev.* 77: 317–331.

Jacoby LL (1991) A process dissociation framework: Separating automatic from intentional uses of memory. *J. Mem. Lang.* 30: 513–541.

James W (1890) *The Principles of Psychology*. New York: Dover.

Jastrow J (1890) *The Time Relations of Mental Phenomena*. New York: Hodges.

Johns EE and Mewhort DJK (2002) What information underlies correct rejections in short-term recognition memory? *Mem. Cogn.* 30: 46–49.

Johns EE and Mewhort DJK (2003) The effect of feature frequency on short-term recognition memory. *Mem. Cogn.* 31: 285–296.

Joordens S and Hockley WE (2000) Recollection and familiarity through the looking glass: When old does not mirror new. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1534–1555.

Kahana MJ (1996) Associative retrieval processes in free recall. *Mem. Cogn.* 24: 103–109.

Kahana MJ and Jacobs J (2000) Interrersponse times in serial recall: Effects of intraserial repetition. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1188–1197.

Kahana MJ and Loftus G (1999) Response time versus accuracy in human memory. In: Sternberg RJ (ed.) *The Nature of Cognition*, pp. 322–384. Cambridge, MA: MIT Press.

Kolers PA and Palef SR (1976) Knowing not. *Mem. Cogn.* 4: 553–558.

Konstantinou I and Gardiner JM (2005) Conscious control and memory awareness when recognising famous faces. *Memory* 13: 449–457.

Kristofferson WW (1972) Effects of practice on character-classification performance. *Can. J. Psychol.* 26: 540–560.

Luce RD (1986) *Response Times: Their Role in Inferring Elementary Mental Organization*. New York: Oxford University Press.

MacLeod CM and Nelson TO (1984) Response latency and response accuracy as measures of memory. *Acta Psychol.* 57: 215–235.

Macmillan NA and Creelman CD (2005) *Detection Theory: A User's Guide*, 2nd edn. Mahwah, NJ: Lawrence Erlbaum Associates.

Malmberg KJ, Holden JE, and Shiffrin RM (2004) Modeling the effects of repetions, similarity, and normative word frequency on old-new recognition and judgments of frequency. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 319–331.

Mandler G (1980) Recognizing: The judgment of previous occurrence. *Psychol. Rev.* 87: 252–271.

Mayberry MT, Parmentier FBR, and Jones DM (2002) Grouping of list items reflected in the time of recall: Implications for models of serial verbal memory. *J. Mem. Lang.* 47: 360–385.
McClelland JL and Chappell M (1998) Familiarity breeds differentiation: A subjective-likelihood approach to the effects of experience in recognition memory. *Psychol. Rev.* 105: 724–760.
McElree B (2001) Working memory and focal attention. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 817–835.
McElree B, Dolan PO, and Jacoby LL (1999) Isolating the contributions of familiarity and source information to item recognition: A time course analysis. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 563–582.
McElree B and Dosher BA (1989) Serial position and set size in short-term memory: The time course of recognition. *J. Exp. Psychol. Gen.* 118: 346–373.
McGill WJ (1963) Stochastic latency mechanisms. In: Luce RD, Bush RR, and Galanter E (eds.) *Handbook of Mathematical Psychology,* vol. 1, pp. 309–360. New York: Wiley.
Metcalfe Eich J (1982) A composite holographic associative recall model. *Psychol. Rev.* 89: 627–661.
Metcalfe J and Murdock BB Jr. (1981) An encoding and retrieval model of single-trial free recall. *J. Verbal Learn. Verbal Behav.* 20: 161–189.
Metlay W, Handley A, and Kaplan IT (1971) Memory search through categories of varying size. *J. Exp. Psychol.* 91: 215–219.
Mewhort DJK and Johns EE (2000) The extralist-feature effect: Evidence against item matching in short-term recognition memory. *J. Exp. Psychol. Gen.* 129: 262–284.
Meyer DE, Irwin DE, Osman AM, and Kounios J (1988) The dynamics of cognition and action: Mental processes inferred from speed-accuracy decomposition. *Psychol. Rev.* 95: 183–237.
Millward R (1964) Latency in a modified paired associate learning experiment. *J. Verbal Learn. Verbal Behav.* 3: 309–316.
Monsell S (1978) Recency, immediate recognition memory, and reaction time. *Cogn. Psychol.* 10: 465–501.
Murdock BB Jr. (1971) A parallel-processing model for scanning. *Percept. Psychophys.* 10: 289–291.
Murdock BB Jr. (1982) A theory for the storage and retrieval of item and associative information. *Psychol. Rev.* 89: 609–626.
Murdock BB Jr. (1985) An analysis of the strength-latency relationship. *Mem. Cogn.* 13: 511–521.
Murdock BB (2003) The mirror effect and the spacing effect. *Psychon. Bull. Rev.* 10: 570–588.
Murdock BB Jr. and Franklin PE (1984) Associative and serial-order information: Different models of operation? *Mem. Cogn.* 12: 243–249.
Murdock BB Jr. and Okada R (1970) Interresponse times in single-trial free recall. *J. Exp. Psychol.* 86: 263–267.
Neisser U (1963) Decision time without reaction-time: Experiments in visual scanning. *Am. J. Psychol.* 76: 376–385.
Nelson TO, Gerler D, and Narens L (1984) Accuracy of feeling-of-knowing judgments for predicting perceptual identification and relearning. *J. Exp. Psychol. Gen.* 113: 282–300.
Nobel PA and Shiffrin RM (2001) Retrieval processes in recognition and cued recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 384–413.
Oberauer K (2003) Understanding serial position curves in short-term recognition and recall. *J. Mem. Lang.* 49: 469–483.
Pachella RG (1974) The interpretation of reaction time in information processing research. In: Kantowitz B (ed.) *Human Information Processing: Tutorials in Performance and Cognition*. New York: Halstead Press.
Patterson KE, Meltzer RH, and Mandler G (1971) Inter-response times in categorized free recall. *J. Verbal Learn. Verbal Behav.* 10: 417–426.
Pollio HR (1964) Composition of associative clusters. *J. Exp. Psychol.* 67: 199–208.
Raaijmakers JGW and Shiffrin RM (1980) SAM: A theory of probabilistic search of associative memory. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 14, pp. 207–262. New York: Academic Press.
Raaijmakers JGW and Shiffrin RM (1981) Search of associative memory. *Psychol. Rev.* 88: 93–134.
Ratcliff R (1978) A theory of memory retrieval. *Psychol. Rev.* 85: 59–108.
Ratcliff R (1988) Continuous versus discrete information processing: Modelling accumulation of partial information. *Psychol. Rev.* 95: 238–255.
Ratcliff R and Murdock BB Jr. (1976) Retrieval processes in recognition memory. *Psychol. Rev.* 83: 190–214.
Reder LM, Nhouyvanisvong A, Schunn CD, Ayers MS, Angstadt P, and Hiraki K (2000) A mechanistic account of the mirror effect for word frequency: A computational model of remember-know judgments in a continuous recognition paradigm. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 294–320.
Roediger HL III, Payne DG, Gillepsie GL, and Lean D (1982) Hyperamnesia as determined by level of recall. *J. Verbal Learn. Verbal Behav.* 21: 635–655.
Roediger HL III, Stellon CC, and Tulving E (1977) Inhibition from part-list cues and rate of recall. *J. Exp. Psychol. Hum. Learn. Mem.* 3: 164–188.
Roediger HL III and Thorpe LA (1978) The role of recall time in producing hyperamnesia. *Mem. Cogn.* 6: 296–305.
Roediger HL III and Tulving E (1979) Exclusion of learned material from recall as a postretrieval operation. *J. Verbal Learn. Verbal Behav.* 18: 601–615.
Rohrer D and Wixted JT (1994) An analysis of latency and interresponse time in free recall. *Mem. Cogn.* 22: 511–524.
Rotello CM and Heit E (1999) Two-process models of recognition memory: Evidence for recall-to-reject? *J. Mem. Lang.* 40: 432–453.
Rotello CM and Heit E (2000) Associative recognition: A case of recall-to-reject processing. *Mem. Cogn.* 28: 907–922.
Schneider W and Shiffrin RM (1977) Controlled and automatic human information processing: I. Detection, search, and attention. *Psychol. Rev.* 84: 1–66.
Schwartz BL (2001) The relation of tip-of-the-tongue states and retrieval time. *Mem. Cogn.* 29: 117–126.
Shiffrin RM (1970) Memory search. In: Norman DA (ed.) *Models of Memory*, pp. 375–447. New York: Academic Press.
Shiffrin RM (2003) Modeling memory and perception. *Cogn. Sci.* 27: 341–378.
Shiffrin RM and Raaijmakers J (1992) The SAM retrieval model: A retrospective and prospective. In: Healy AF, Kosslyn SM, and Shiffrin RM (eds.) *From Learning Processes to Cognitive Processes: Essays in Honour of William K. Estes,* vol. 1, Potomac, MD: Erlbaum.
Shiffrin RM and Steyvers M (1997) A model for recognition memory: REM – Retrieving effectively from memory. *Psychon. Bull. Rev.* 4: 145–166.
Sirotin YB, Kimball DR, and Kahana MJ (2005) Going beyond a single list. Modeling the effects of prior experience on episodic free recall. *Psychon. Bull. Rev.* 12: 787–805.
Sternberg S (1966) High-speed scanning in human memory. *Science* 153: 652–654.
Sternberg S (1969) Memory-scanning: Mental processes revealed by reaction-time experiments. *Am. Sci.* 57: 421–457.
Sternberg S (1975) Memory scanning: New findings and current controversies. *Q. J. Exp. Psychol.* 27: 1–32.
Tulving E (1985) Memory and consciousness. *Can. Psychol.* 26: 1–12.

Van Zandt T and Townsend JT (1993) Self-terminating versus exhaustive processes in rapid visual and memory search: An evaluative review. *Percept. Psychophys.* 53: 563–580.
Verde MF and Rotello CM (2004) Strong memories obscure weak memories in associative recognition. *Psychon. Bull. Rev.* 11: 1062–1066.
Welford AT (1980) *Reaction Times*. London: Academic Press.
Wickelgren WA (1977) Speed-accuracy tradeoff and information-processing dynamics. *Acta Psychol.* 41: 67–85.
Wickelgren WA and Corbett AT (1977) Associative interference and retrieval dynamics in yes-no recall and recognition. *J. Exp. Psychol. Hum. Learn. Mem.* 3: 189–202.
Wickelgren WA, Corbett AT, and Dosher BA (1980) Priming and retrieval from short-term memory: A speed-accuracy tradeoff analysis. *J. Verbal Learn. Verbal Behav.* 19: 387–404.
Wickelgren WA and Norman DA (1966) Strength models and serial position in short-term recognition memory. *J. Math. Psychol.* 3: 316–347.
Wingfield A, Lindfield K, and Kahana MJ (1998) Adult age differences in temporal characteristics of category free recall. *Psychol. Aging* 13: 256–266.
Wixted JT and Rohrer D (1994) Analyzing the dynamics of free recall: An integrative review of the empirical literature. *Psychon. Bull. Rev.* 1: 89–106.
Wixted JT and Stretch V (2004) In defense of the signal detection interpretation of remember/know judgments. *Psychon. Bull. Rev.* 11: 616–641.
Yonelinas AP (1994) Receiver-operating characteristics in recognition memory: Evidence for a dual-process model. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 1341–1354.
Yonelinas AP (2002) The nature of recollection and familiarity: A review of 30 years of research. *J. Mem. Lang.* 46: 441–517.

# 2.25 Mathematical Models of Human Memory

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## 2.25.1 Introduction

In this chapter, I will provide a brief introduction to formal models of memory. Although such approaches have become quite successful, it would be an overstatement to say that they enjoy a great popularity among mainstream experimental researchers interested in human memory processes. There are probably several reasons for this skepticism, but an important one seems to be that it is not always easy to see what a model adds compared to a verbal theory or explanation. In this chapter, I will discuss a number of the most important theoretical approaches, paying special attention to the issue of what these models can do that could not be done using only verbal theorizing.

Formal or mathematical models of memory can be broadly classified in terms of their scope and generality. At the simplest end, we have descriptive models that try to characterize lawful empirical regularities. Memory researchers, for example, have tried to characterize the form of the forgetting function, the function that relates memory performance (percent recalled or some other measure) to the retention interval, the time since the item was studied. Although several promising candidate functions have been proposed (most notably power and logarithmic functions; see Wixted and Ebbesen, 1991), the issue of which function best describes the forgetting curve has not been resolved. One reason is that many candidate functions capture the basic aspects of the forgetting curve, i.e., a curve that is characterized by a decreasing rate of decline (the older the trace, the less likely it is that it will be forgotten in the next unit of time). Another reason is that the comparison between different functions is complicated by the fact that some models are more versatile than others (can handle more different shapes, can mimic data generated by other models), which means that it is easier for such a model to fit any given set of data, although at the expense of its generalizability to new data (for a discussion of these issues, see Lee (2004) and Myung and Pitt (2002)). Hence, although such descriptive models may be useful for predictive purposes, a shortcoming of these models is that they are limited in scope, predicting only one type of relation. What is lacking in such models is an account of what causes the forgetting, making it difficult to devise experimental tests that would pit one model against the other. Similar issues arise in attempts to model the learning curve, the function that describes the increase in performance as a function of the number of learning or training trials.

At the next level, we have models that try to account for the basic learning and forgetting data in terms of what happens to individual memory traces. One issue that the descriptive models usually do not discuss is whether the proposed forgetting (or learning) function describes each and every memory trace or just the average of a large number of separate curves. This question was the main focus of a large number of studies conducted in the 1950s and 1960s. In a series of studies using the so-called RTT paradigm, in which one study or reinforcement trial (R) was followed by two test trials (T) without any additional study in between, it was shown that the probability of a correct response (success) on the second test trial given no success at the first test trial was nearly zero and much lower than the average probability of a success. This seemed to be indicative of one-trial or all-or-none learning: The item was either completely learned on the study trial or not at all. This contradicted the standard assumption that learning was gradual. Such gradual learning functions were predicted by so-called linear operator models that assumed that the probability of a success on a given trial $n$ was a simple linear function of the probability of success on the previous trial. Thus,

$$p_{n+1} = Q(p_n) = \alpha p_n + \beta \qquad [1]$$

where $\alpha$ and $\beta$ are parameters that depend on the nature of the reinforcement given on trial $n$. The crucial assumption here was that this function described the behavior of each and every item independent of whether the response to that item had been correct on trial $n$.

To account for the results of the RTT paradigm, an alternative model was proposed in which the learning of an item was all-or-none: The item was either learned, always leading to a correct response, or not learned, in which case the probability of a success was at chance level. This model still predicts a gradual learning curve because such a curve represents the average of a number of items and subjects, each with a different moment at which learning takes place. The learning process in the all-or-none model may be represented by a simple Markov chain with two states, the conditioned or learned state ($L$) in which the probability correct is equal to 1, and the unconditioned state ($U$) in which the probability correct is at chance level (denoted by $g$). The following matrix gives the transition probabilities, the probabilities of going from state $X$ ($L$ or $U$) on trial $n$ to state $Y$ on trial $n+1$.

state on trial $n+1$ P(Correct)

$$\begin{array}{c} \\ L \\ U \end{array}\begin{array}{c} \begin{array}{cc} L & U \end{array} \\ \begin{bmatrix} 1 & 0 \\ c & 1-c \end{bmatrix} \end{array} \begin{array}{c} \\ \begin{bmatrix} 1 \\ g \end{bmatrix} \end{array} \qquad [2]$$

state on trial $n$

Strong support for the all-or-none model was obtained in an experiment by Bower (1961) in which subjects were presented lists of ten paired associate items consisting of a consonant pair and either the digit 1 or 2. This experiment was a breakthrough in the mathematical modeling of learning and memory because it did not just fit the learning curve but also a large number of other statistics (such as the distribution of the number of errors and of the trial of last error). The model fitted Bower's data remarkably well and this set a new standard for mathematical modelers.

One of the key predictions of the model was what became known as presolution stationarity: If the all-or-none assumption holds, the probability of responding correctly prior to learning (or prior to the last error) had to be constant:

$$P(e_{n+1}|e_n) = \text{constant for all } n \qquad [3]$$

Figure 1 shows the data from Bower's (1961) experiment and the predictions from the all-or-none and linear models. The data are in almost perfect agreement with the predictions of the all-or-none model and clearly inconsistent with those of the linear model. It may be shown that this presolution stationarity property is crucial for the all-or-none model in that the combination of this property together with the distribution of the trial of last error is a sufficient condition for the all-or-none model. That is, if both of these properties hold, the all-or-none model has to be the correct model. Since this property is strong evidence for the all-or-none model, it is understandable that proponents of gradual learning models tried to reconcile the finding with a model in which learning was more gradual. The argument that was used was based on the idea that the result might be explained if individual differences in the speed of learning were assumed. If items and/or subjects differ in their learning rate, errors on later trials might be

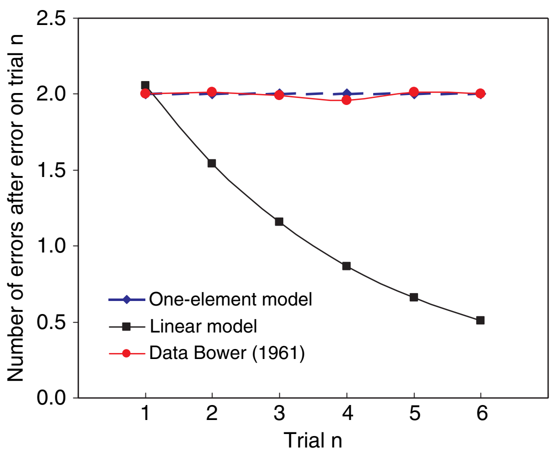


**Figure 1** Number of errors following an error on trial *n* as a function of *n*. Data from Bower GH (1961) Application of a model to paired-associate learning. *Psychometrika* 26: 255–280; predictions for the all-or-none model and the linear model.

coming mainly from the more difficult items and from subjects with slower learning rates. However, in an ingenious analysis, Batchelder (1975) showed that this could not work. Batchelder analyzed the predictions of the linear operator model (eqn [1]) using a completely arbitrary distribution for the learning rate parameter and proved that it was impossible for the linear operator model to fit these results.

The success of the all-or-none model soon led to a series of related models that were based on the notion of discrete changes in the state of studied items. One issue that was investigated was whether this notion could account for transfer effects based on underlying conceptual categories. For example, suppose that several lists of paired associates are learned in succession where the stimulus items that belong to a particular conceptual category all have the same response. If learning is all-or-none, we might assume that a particular item will be learned in an all-or-none fashion as long as the conceptual relation is not yet discovered, but that once the relation has been discovered (which itself involves an all-or-none process) any new item belonging to the same category will start in the learned state rather than the unlearned state (i.e., no errors will be made on this item). Greeno and Scandura (1966), Batchelder (1970), and Polson (1972) showed that a relatively simple generalization of the all-or-none model gave a good account for the results of such experiments.

Although the all-or-none model was quite successful, the experiments that it was applied to were extremely simplified (simple stimuli, coupled with one of two possible responses). From the outset it was clear that the model would not hold for more complex experiments. However, perhaps the basic idea of the all-or-none model could be generalized in such a way that more complex learning tasks might be described as involving a series of stages, each stage being completed in an all-or-none manner. The most successful attempt at this type of generalization of the all-or-none model can be seen in the work of Greeno and associates (Greeno, 1968, 1974; James and Greeno, 1970; Humphreys and Greeno, 1970). Greeno did an extensive theoretical and empirical analysis of a two-stage learning model. As there are now two learning rate parameters, one for each stage, it becomes possible to look at the factors that affect each of these parameters and hence provide an interpretation for what the separate stages stand for. Contrary to the traditional two-stage theory of paired-associate learning (Underwood and Schulz, 1960), which maintained that the first stage involved a process of response learning and the second stage stimulus–response association, the results from the two-stage model proposed by Greeno were largely consistent with the idea that the first stage involved storage of the pair and the second stage learning to retrieve the pair.

Perhaps the most significant extension of the all-or-none model was proposed by Atkinson and Crothers (1964), who included the notion of a short-term memory state. The assumption here was that an item could move to a short-term state when it was studied but that it could move back to the unlearned state on subsequent trials when other items were being studied. Thus, such an item would show short-term forgetting: When tested immediately after having been studied, the response would be correct; however, when retested after several intervening trials, the probability of a correct response would be back at the baseline level (unless the item had moved to the learned state). The learning process in such models can be described using two transition matrices, one that applies when the target item is presented ($\mathbf{T_1}$) and one that applies when another item is presented ($\mathbf{T_2}$):

$$\mathbf{T}_1 = \begin{array}{c} \\ L \\ S \\ U \end{array} \begin{array}{c} \begin{array}{ccc} L & S & U \end{array} \\ \begin{bmatrix} 1 & 0 & 0 \\ d & 1-d & 0 \\ wc & w(1-c) & (1-w) \end{bmatrix} \end{array} \qquad [4a]$$

$$\mathbf{T}_2 = \begin{array}{c} \\ L \\ S \\ U \end{array} \begin{array}{c} \begin{array}{ccc} L & S & U \end{array} \\ \begin{bmatrix} 1 & 0 & 0 \\ (1-f)r & (1-f)(1-r) & f \\ 0 & 0 & 1 \end{bmatrix} \end{array} \qquad [4b]$$

where $L$ is the state in which the item has been learned, $S$ is the short-term memory state, and $U$ is the state in which the item is not learned.

Several variants of such LS-models (Long-Short) were introduced, including ones that assumed that there could be additional storage (as well as forgetting) on intervening trials (note the parameter $r$ in $\mathbf{T_2}$). This notion is of course related to the more general concepts of rehearsal and consolidation. The idea of storage on trials intervening between presentations might provide an explanation for the spacing effect, the finding that (in general) spaced study presentations are more beneficial for later recall than massed presentations. Bjork (1966), Rumelhart (1967), and Young (1971) developed (increasingly complex) models to account for such spacing effects in paired-associate recall, leading to a model that became known as the General Forgetting Theory. However, these models never gained much popularity, perhaps because they were introduced at a time when the emphasis in the formal modeling of memory processes shifted to the next level following the 1968 publication of the Atkinson-Shiffrin model.

The theoretical framework that was proposed by Atkinson and Shiffrin (1968) made a distinction between structural properties of the memory system that were fixed and permanent, and control processes that operated on those structures. Control processes included such processes as rehearsal, coding, and retrieval strategies. The Atkinson-Shiffrin model assumed that information first enters a Short-Term Store (STS) and that the processing within STS determines storage in a permanent memory system, Long-Term Store (LTS). Information that is still present in STS at the time of testing will be readily available, but information that is no longer in STS will have to be retrieved from LTS. The probability of successful retrieval from LTS was a function of the strength of the LTS trace, which was itself determined by the nature of the processing in STS.

An important advancement of the Atkinson-Shiffrin theory was the model that was proposed for rehearsal processes in STS. It was assumed that at any time only a few items could be simultaneously in STS and that once STS was filled, any new item would have to replace one of the other items in STS. This idea led to the introduction of the concept of a rehearsal buffer as a simple model for rehearsal in STS, or rather a family of models since various alternatives were considered that differed in whether older items were more or less likely to be replaced by a new item. In these models, it was assumed that storage in LTS is directly related to the length of time that a particular item stays in the buffer. This storage assumption has often been misinterpreted as implying that the Atkinson-Shiffrin theory would assume that only time in STS determines how much information gets stored in LTS. However, Atkinson and Shiffrin proposed that rehearsal in STS is a control process and that the nature of the processing in STS will vary depending on the requirements of the task. In some tasks, the emphasis will be on simply maintaining the information in STS, but in other tasks the emphasis is on coding the information in LTS. This distinction between coding and rehearsal (or elaborative and maintenance rehearsal as it was later called) made it possible to accommodate levels-of-processing effects, i.e., the notion that the nature of the processing in STS determines the probability of later recall. Thus the standard textbook story that supposes that there is a fundamental difference between the Two-Store model and the levels-of-processing framework proposed by Craik and Lockhart (1972) is incorrect (see also Raaijmakers, 1993).

The major significance of the Atkinson-Shiffrin model was that it was not simply a model for one specific experimental task but a general framework within which models could be formulated for specific tasks. Thus, in addition to the short-term memory tasks investigated in the 1968 paper, the same general framework was applied to search and retrieval processes in long-term memory (see Shiffrin, 1968; Shiffrin and Atkinson, 1969), free recall (Shiffrin, 1970), and recognition memory (Atkinson and Juola, 1974). This was a major step forward compared to, for example, the General Forgetting Theory that did not allow a simple generalization to free recall or recognition paradigms. This type of approach in which a general framework is presented within which specific models are developed for specific tasks is a common characteristic of most current models of memory. In the next sections, I will discuss a number of such approaches with special attention given to the question how these models are able to provide novel explanations for experimental findings.

## 2.25.2 The ACT Model

The first model that we will discuss in more detail is the ACT theory developed by John Anderson. The ACT theory (Adaptive Control of Thought) has its roots in early theories of spreading activation (Collins and Loftus, 1975) and the work of Newell and Simon on cognitive architectures. ACT is not just a model for memory processes but aims to provide a general framework or architecture for all cognitive tasks (sometimes termed a Unified Theory for Cognition). Although ACT has undergone many changes since it was first presented in 1976, there are a number of aspects of the theory that have remained more or less the same over the years. First, ACT does not make a fundamental distinction between semantic and episodic memory. All knowledge facts and all experiences are stored in a single declarative memory system. Second, ACT makes a distinction between a working memory system, a declarative memory system, and a procedural memory system. Declarative memory is modeled as a large set of interconnected nodes or chunks, while the procedural system has the form of a large set of production rules (rules of the form IF conditions A, B, and C are satisfied, THEN action Y is performed) that fire whenever their conditions are satisfied. Although one sometimes gets the impression that ACT is more a programming language in which various cognitive tasks may be modeled, the ACT framework has been used to develop detailed quantitative models for various memory tasks that do make specific and testable predictions.

In the original ACT model (Anderson, 1976), retrieval of a target item B from a cue item A was based on a notion of spreading activation in which a particular node was either active or inactive. The spreading of activation was controlled by the relative strength of the links from the cue to the nodes that were connected to the cue node. Once a node was activated, it would in turn start to activate other nodes associated with it (a threshold was assumed to prevent activation of all nodes). Since activation is all-or-none, response latency was determined by the time it took for activation to spread to the target node. However, using a primed lexical decision task, Ratcliff and McKoon (1981) showed that the semantic distance between the prime and the target does not affect the time at which the facilitation due to priming begins to have its effect, although it does affect the magnitude of the facilitation. Anderson (1983a,b) proposed a revised version of ACT, named ACT*, in which nodes were no longer activated in an all-or-none fashion. In ACT*, each node had a continuously varying activation value. The larger the activation value, the faster and the more likely it was that the trace would be retrieved.

Anderson (1981, 1983b) showed how this model could be used to explain a number of memory phenomena. In ACT*, performance is determined by the strength of the target trace relative to that of other traces associated with the retrieval cues used. On each presentation of an item, there is a probability that a trace will be formed and once formed, further presentations provide additional strength to the trace. The strength added to a trace was assumed to decay according to a power law. More specifically, the trace strength ($S$) for a trace that has been strengthened $n$ times is equal to:

$$S = \sum_{i=1}^{n} t_i^{-b} \quad [5]$$

where $t_i$ is the time since the $i$-th strengthening and $b$ is a decay parameter (between 0 and 1).

Anderson (1981, 1983b) showed that the ACT* model predicts a large number of standard findings from the memory literature. One intriguing result that came out of this analysis was that performance in recall tasks is a function of both the absolute and the relative strength of the target trace. In ACT*, the probability of recall is a function of both relative and absolute strength, but the latency is a function of the relative strength only. Anderson (1981) demonstrated that this implies that in a standard interference task there will be an interference effect on latency, even when the conditions are equated on percent correct. This result implies that it will not be possible to completely equate interference and control conditions at the end of second-list learning, as was implicitly assumed in many experiments on interference and forgetting (e.g., when both conditions learn to the same criterion). Basically, this prediction is due to the fact that if probability of recall is a function of both relative and absolute strength, it must be the case that in the condition in which it takes longer to reach a particular recall criterion, the absolute strength will be larger at the point where the criterion is reached. Hence, to get equal percent recall, this must be compensated for by a lower relative strength, hence a longer latency.

In a similar way, it can be shown that if the second list is again learned to a fixed criterion, performance on the second list may show proactive facilitation instead of interference, when it is tested after a delay in such a way that differences in relative strength are less important and performance is mostly determined by the absolute strength of the target trace. The latter may be experimentally accomplished by giving an unpaced test in which subjects are given ample time to produce the response. In such a test, differences in relative strength become less important since eventually the trace will be retrieved, although it may take a long time. Anderson (1983b) reports results that confirm this counterintuitive prediction. Mensink and Raaijmakers (1988) showed that these predictions hold not only for the ACT* model, but for all models in which performance is a function of both relative and absolute strength.

The latest version of ACT, called ACT-R (ACT-Rational), is based on a number of assumptions that are quite different from ACT*, yet the model shares enough features with the older models to justify using the same acronym. There are two important differences with ACT*. First, ACT-R no longer assumes a spreading activation conception of memory retrieval. Rather, it is assumed that activation of a memory trace or chunk is a direct function of the association between the source elements (the retrieval cues) to that chunk and there is no spread of activation to other chunks from a chunk that is not itself a source of activation. Second, ACT-R is based on the assumption that the cognitive system is a rational system, i.e., the rules that govern the activation of information from memory are such that they optimize the fit to the environmental demands. This rational approach to cognition has been very influential (see also more recent models such as the REM model (Shiffrin and Steyvers, 1997) that will be discussed later in this chapter).

To appreciate this rational approach, it is helpful to consider some of the results discussed by Anderson and Schooler (1991). Anderson and Schooler showed that many of the functional relationships that we know from standard memory experiments (e.g., the typical learning and forgetting functions) can also be seen in the environment with material that has little to do with memory *per se*. For example, the probability that a particular word will appear in the headline of *The New York Times* or the probability that one will get an e-mail from a specific person obey the same functional relations as we know from memory research. If a particular word has appeared in the headline the probability that it will appear again after X days follows the same power law that we are familiar with when looking at standard retention functions. Thus, the basic idea of ACT-R is that the cognitive system has developed in such a way as to provide an optimal or rational response to the information demands of the environment: The probability that a particular item will be remembered at a particular time reflects the probability that it will be needed at that time.

This rational approach is reflected in the equations that ACT-R uses to describe the activation of a particular trace given that specific cues are present. In the ACT-R approach to memory (see Anderson et al., 1998) it is assumed that the activation of a chunk $i$ depends both on its base-level activation ($B_i$, a function of its previous use) and on the activation that it receives from the elements currently in the focus of attention:

$$A_i = B_i + \sum_j W_j S_{ji} \qquad [6]$$

where $S_{ji}$ is the strength of the association from element $j$ to chunk $i$ and $W_j$ is the source activation (salience) of element $j$. If we interpret the base-level activation as similar to the prior odds of the chunk being needed and the second term as similar to the (log) likelihood of the trace given the available evidence (the cues), then the similarity of eqn [6] to Bayes' rule becomes evident. (According to this rule, the logarithm of the posterior odds is equal to the log prior odds plus the log likelihood ratio.) According to ACT-R,

$$S_{ji} = S + \ln(P(i|j)) \qquad [7]$$

where $P(i, j)$ is the probability that chunk $i$ will be needed when element $j$ is present or active. Note that since $P(i, j) \leq 1$ the logarithm of $P(i, j)$ will be $\leq 0$ and hence $S$ represents the maximum value that $S_{ji}$ can obtain. For all practical purposes, these $S_{ji}$ may be viewed as reflecting the associations between the cues $j$ and the target trace. In ACT-R (see Anderson et al., 1998: 344), it is typically assumed that if there are $m$ elements associated to the cue $j$, each will have a probability of $1/m$, hence:

$$S_{ji} = S + \ln(1/m) = S - \ln(m) \qquad [8]$$

Note that this equation assumes that for the associative activation $S_{ji}$ it does not matter that a particular association may have become stronger in the course of the experiment: all that matters is the number of associative links from the cue to other elements or its fan. This seems a rather strong assumption, yet it does play an important role in ACT-R's handling of data from recognition experiments.

The first part of eqn [6], the base-level activation, reflects the activation that remains from previous presentations of the target trace or chunk. The activation of a chunk is subject to decay so that the longer ago the chunk was strengthened, the less the contribution of that activation to the current base-level activation. The equation for the base-level activation is thus given by:

$$B_i = \ln\left(\sum_{j=1}^{n} t_j^{-d}\right) + B \qquad [9]$$

In this equation, $n$ is the number of times the chunk has been retrieved from memory, $t_j$ indicates the length of time since the $j$-th presentation or rehearsal, and $d$ and $B$ are constants. It is evident that eqn [9] is closely related to eqn [5] that describes the activation in ACT*.

Finally, as in ACT*, it is assumed that the latency of a response is an exponentially decreasing function of the activation level of the corresponding chunk. However, unlike ACT*, ACT-R does not simply look at the activation of the target trace but takes into account other traces or chunks that might be activated. It is assumed that the system will always retrieve the chunk with the highest activation (provided it is above the threshold). Due to the presence of noise in the system, the activation values will not have a fixed value but rather a probability distribution (a logistic distribution is assumed). The probability that a chunk with a mean activation value of $A_i$ (and variance $\sigma^2$) is above a threshold $\tau$ is then equal to:

$$\Pr(i) = \frac{1}{1 + \exp[(A_i - \tau)/s]} \quad \text{where } s = (\sigma\sqrt{3})/\pi \qquad [10]$$

If there are more chunks above threshold, the system will choose the one with the largest activation. The probability that the target chunk has the largest activation is given by an equation similar to the Luce choice rule:

$$P(choose\ i) = \frac{\exp(A_i/t)}{\sum_j \exp(A_j/t)} \quad \text{where } t = (\sigma\sqrt{6})/\pi \qquad [11]$$

Although ACT-R is much more than a model for memory, it does explain quite a number of findings from the memory literature. We will briefly discuss two such applications, the analysis of recognition memory proposed by Anderson et al. (1998) and the model for spacing effects developed by Pavlik and Anderson (2005).

Any ACT-R model begins with the specification of a number of production rules. In the recognition model, the basic production rules are the rules for Yes and No responses, which simply state that if a trace is found that corresponds to seeing the item in the list context, a Yes response will be made and another rule that applies when the first one fails and that generates a No response. Hence, contrary to most other current models for recognition, ACT-R is not based on a signal-detection-like approach but rather on the retrieval of a trace representing the item in the list context. Note that in such a model negative responses (No responses) are not based on a low familiarity value but on the fact that the rule for generating a positive response passes a waiting time threshold. Although such an approach may work well for explaining data observed on positive responses, there are some problems when negative responses are to be explained. First, this type of model has no simple solution to generate fast negative responses. Second, the model predicts that negative responses are not affected by various experimental factors (e.g., list length) unless one assumes that the waiting time threshold itself is a function of those factors (a solution that is hard to defend).

According to ACT-R, performance in a standard recognition task is determined by the activation of the chunk representing the tested item. According to eqn [6], this is a function of the base-level activation and the associative activation that it receives from the cues (the presented word and the list context). Hence,

$$A = \ln\left(\sum_{j=1}^{n} t_j^{-d}\right) + B + W_W S_W + W_L S_L \qquad [12]$$

where $W_W$ is the weighting given to the word, $S_W$ is the strength of the association from the word to the trace, $W_L$ is the weight of the list context, and $S_L$ is the strength of the context association. According to Anderson et al. (1998: 348), the first term may be approximated by:

$$\ln\left(\sum_{j=1}^{n} t_j^{-d}\right) = \ln\left(\frac{anT^{-d}}{1-d}\right) = C + \ln(n) - d\ln(T) \qquad [13]$$

where C captures the constant terms. Since $W_W S_W$ is also a constant and $S_L$ is equal to $S - ln(L)$ according to eqn [8], the activation of eqn [12] may be written as:

$$A = B' + \ln(n) - d\ln(T) - W_L \ln(L) \qquad [14]$$

where $B'$ combines all the constant effects, $n$ equals the number of presentations/rehearsals, $T$ is the time since presentation, $L$ is the list length, $d$ is the decay rate, and $W_L$ is the attentional weighting of the list context. In their analyses, Anderson et al. (1998) set $d$ and $W_L$ equal to 0.5.

One interesting finding that this model predicts (and that would have been difficult to foresee without actually running the simulations) is the differential effect of list length and list strength in recognition. The list length effect refers to the effect of the number of other items on the list, while the list-strength effect refers to the effect of the strength of those other items (where strength might be manipulated by such factors as presentation time or additional presentations). In recall paradigms, both of these effects are present but in recognition tasks there is no effect of list strength (or a slightly reversed effect), although there is a list-length effect. Shiffrin et al. (1990) showed that it is very difficult for many models to predict both the presence of an effect of the number of other items, yet no effect of the strength of those other items. ACT-R's recognition model, however, does explain this intricate pattern of results. The basic reason is that in ACT-R, strength manipulations affect the base-level activations whereas the length of the list mainly affects the associative activation (i.e., the fan effect; see eqn [13]). There are a few other factors that play a role (such as small differences in retention interval when presentation time or the length of the list is varied) but the main effects are due to these two factors. Hence, increases in strength affect the base-level activation for the tested item but do not affect the interfering effect of the other items on the list. Of course, one might question the assumption that strength manipulations do not affect the associative activation (as was the case in ACT*), but even so, the ACT-R analysis points to a possible solution to the puzzle of length and strength effects, a pattern of results that has proved difficult to accommodate in other models for recognition.

Pavlik and Anderson (2005) presented an application of ACT-R to account for spacing effects in paired associate recall tasks. They showed that their model could account for all of the standard findings in the spacing literature including a new experiment that they performed in which spacing was varied over much longer intervals than is normally the case in these experiments. In their experiment, there were two sessions separated by 1 or 7 days. During the first session, the subjects learned the English translations for a number of Japanese words. The pairs were presented four or eight times during the first session with interpresentation spacings of two, 14, or 98 trials. During the second session, they were given a number of test trials on the pairs learned during the first session. The data showed a crossover interaction such that the shorter spacings led to better performance at the end of the first session but worse performance at the start of the second session (see **Figure 2**).

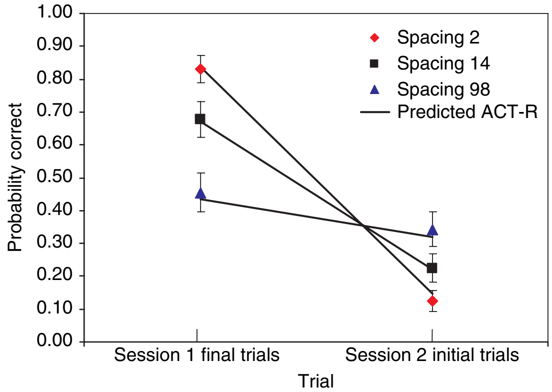


**Figure 2** Probability of a correct response before and after the retention interval as a function of the spacing between the presentations during session 1. Observed data from Pavlik PI and Anderson JR (2005) Practice and forgetting effects on vocabulary memory: An activation-based model of the spacing effect. *Cogn. Sci.* 29: 559–586; predictions from the ACT-R model. Error bars correspond to two standard errors.

In the application of ACT-R to this experiment, the associative activation will be constant and hence the analysis focuses on the base-level activation. Without any modifications, the ACT-R model does not predict such spacing effects (Pavlik and Anderson, 2005: 570), so some changes are necessary. The most likely candidate is the decay rate parameter $d$ (see eqn [9]). In order to account for spacing effects, the decay rate has to be made sensitive to the intervals between successive presentations. The formulation that Pavlik and Anderson (2005) used is based on the assumption that the decay rate for the contribution from the $j$-th presentation is a function of the activation at the time of the $j$-th presentation. Thus, eqn [9] is replaced by the following equation for the activation after $n$ presentations:

$$B_n = \ln\left(\sum_{j=1}^{n} t_j^{-d_j}\right) \textit{ with } d_j = ce^{B_{j-1}} + a \qquad [15]$$

If at the start of the $j$-th presentation the activation was high (i.e., the activation after $j$–1 presentations, $B_{j-1}$), $d_j$ will be larger and thus the contribution from that trial at later tests will be lower due to the more rapid decay. Hence, the effect of long spacing intervals (characterized by low activation at the end of the retention interval) will be longer lasting and this more than compensates for their longer retention intervals, thus leading to a spacing effect.

These two examples illustrate the way in which task-specific models are constructed within the ACT-R framework. As mentioned before, ACT-R is an ambitious attempt to provide a unified theory of cognition. As such, restricting the evaluation to just its contribution as a memory model clearly does not do justice to the theory as a whole. However, even though the ACT-R has not been evaluated as extensively as some of the other memory models, the theory has already made a large number of contributions (see Anderson et al., 1998; Pavlik and Anderson, 2005). There have also been extensions of the framework to implicit memory effects, but these need to be investigated more thoroughly to determine whether they are indeed viable explanations of priming effects. A recent extension of the ACT-R framework is the identification of specific modules within ACT-R with specific regions in the brain. Anderson and colleagues (Anderson et al., 2003, 2004, 2005) have shown that the duration of those components can be mapped onto the BOLD response obtained in the associated brain regions (using the assumption that the duration but not the intensity of a specific component is reflected in the BOLD response). This of course opens up a whole new approach to the validation of the general ACT-R theory and also provides a much-needed theoretical framework for the interpretation of neuroimaging data. All in all, then, ACT-R represents an excellent example of the trend toward more general theories that has characterized recent research on mathematical models for memory processes.

## 2.25.3 The SAM and REM Models

### 2.25.3.1 The SAM Model and Related Models

The next model that we will discuss is the SAM model (Raaijmakers and Shiffrin, 1980, 1981b) and a number of related models that have been proposed in recent years. The SAM model (Search of Associative Memory) started out as a model for free recall (Raaijmakers, 1979). It was soon realized that the model could be generalized to paired-associate recall (Raaijmakers and Shiffrin, 1981a) and recognition (Gillund and Shiffrin, 1984). The model was subsequently extended to handle interference and forgetting (Mensink and Raaijmakers, 1988, 1989) and, more recently, spacing effects (Raaijmakers, 2003). Related models in which a semantic memory component was added have been proposed by other researchers, e.g., PIER2 (Nelson et al., 1998) and eSAM (Sirotin et al., 2005). In addition, Shiffrin and coworkers have developed a new model, REM, that is in many ways similar to SAM, but provides a solution to some problems relating to recognition memory, and that has also been extended to semantic and implicit memory paradigms (Shiffrin and Steyvers, 1997; Schooler et al., 2001; Wagenmakers et al., 2004).

The original SAM model was based on a search model proposed by Shiffrin (1970). It shared a number of characteristics with the Atkinson-Shiffrin theory such as the notion of a STS buffer as a model for rehearsal processes and the assumption that storage in LTS is a function of the nature and duration of rehearsal in STS. SAM assumes that when a specific event occurs (this could be anything but in most analyses it is simply the presentation of an item on a study list) various types of information are stored in the memory trace representing that event. Any type of information might be stored in the trace (the memory image, as it is usually called in SAM), but the model uses a classification in item, associative (interitem), and contextual information. Retrieval of information from LTS is a cue-dependent process, i.e., what is retrieved from LTS depends on the information that is present in STS at the time of the retrieval. In applications of SAM to typical memory paradigms such as free recall or recognition, the cues may be words from the studied list, category cues, and contextual cues.

Whether or not a specific memory trace is retrieved depends on the relations between the cues and the information stored in the trace. These relations are defined in a retrieval structure, a matrix that gives the associative strengths between possible cues and the stored memory image. A crucial assumption in SAM is that when several cues are used simultaneously (e.g., context and a retrieved item), the overall strength of the set of cues ($Q_1$, $Q_2$, etc.) to a specific trace is given by the product of the individual associative strengths:

$$A(i) = \prod_{j=1}^{m} S\left(Q_j, I_i\right) \qquad [16]$$

where $A(i)$ is the combined strength or activation of image $I_i$, and $S(Q_j, I_i)$ is the strength of association between cue $Q_j$ and image $I_i$. The most important aspect of this eqn [16] is the assumption that individual cue strengths are combined multiplicatively into a single activation measure. This multiplicative feature focuses the search process on those memory traces that are strongly associated with all cues, the intersection of the sets of traces activated by each cue separately. An important aspect of SAM is that retrieval strategies are implemented in the choice of retrieval cues but once a specific set of retrieval cues is used, the retrieval process is automatic and completely determined by the relations between the retrieval cues and the information stored in memory.

The activations $A(i)$ determine both the probability of retrieval of a memory trace in recall tasks as well as the probability that an item will be recognized as having been presented on the study list. It is assumed that in recall tasks the probability of being able to generate the answer depends on selecting or sampling the correct target trace and on the probability that enough relevant features from the stored trace are activated to enable the reconstruction or recovery of the answer. It is assumed that the system may sample several times before giving up, but if recovery fails once sampled, it will fail again if the same trace is sampled a second time using the same cues.

More specifically, the probability of sampling a trace is assumed to be proportional to the activation strength of the trace:

$$P_S(I_i) = \frac{A(i)}{\sum A(k)} \quad [17]$$

The probability of recovery is assumed to be an exponential function of the summed strengths of the retrieval cues to the sampled image:

$$P_R(I_i) = 1 - \exp\left[-\sum_{j=1}^{m} S\left(Q_j, I_i\right)\right] \quad [18]$$

Combining these assumptions, an equation can be derived that gives the probability of recall for a simple cued recall test in which the same set of cues is used for a maximum of *Lmax* retrieval attempts:

$$P_{recall}(I_i) = \left[1 - (1 - P_s(I_i))^{L_{\max}}\right] P_R(I_i) \quad [19]$$

The above equations apply to cued recall. SAM was, however, initially developed as a model for free recall, which is more complicated since during the search process other list items may be retrieved and these may then be used as new retrieval cues. In SAM it was assumed that during the presentation of the list items, a few items may be simultaneously rehearsed and that storage of context, item, and interitem information was a function of this rehearsal process. That is, the amount of information that is stored for an item was assumed to be a function of the time that that item was rehearsed or the time that a specific pair was simultaneously rehearsed (in case of the interitem associations). For this part of the model, a buffer model similar to that of Atkinson and Shiffrin (1968) was used. At the time of testing, any items still in the buffer are first recalled (unless of course there are no items available anymore in the buffer) and then the process of retrieval from LTS itself starts. Initially, the search process is based solely on the context cues that are available but as soon as a list item is retrieved, that item is used as an additional cue. If this item+context search is not successful (i.e., if there are *Lmax* consecutive retrieval attempts that do not lead to new items being recalled) the system will revert back to using only the context cue. This process continues until no more new items can be recalled (within a reasonable time). For this latter aspect, a stopping criterion was used based on the total number of failed retrieval attempts (*Kmax*), but other stopping rules are also possible (although we have not seen a case where the nature of the stopping rule seems to matter). SAM also assumes that new information may be stored during the retrieval process. That is, if a new item is successfully retrieved, the associative connections between the probe cues and the sampled image are strengthened. Although conceptually simple, it turns out to be virtually impossible to derive analytical predictions for the model for free recall, hence all analyses have been done using Monte Carlo simulations.

Raaijmakers and Shiffrin (1980) reported a large number of such simulation results and showed that the SAM model gave an excellent account of many standard findings from the free recall literature. These included serial position curves, the effects of list length and presentation time, cumulative recall data, the phenomenon of hypermnesia, and many others. As an example, **Figure 3** gives the predictions from SAM and the observed data for the experiment of Roberts (1972) in which presentation time and list length were varied over a wide range.

Of particular interest was the prediction by SAM of the part-list cuing effect (extensively discussed in Raaijmakers and Shiffrin, 1981b). This effect refers to the finding that presenting a random sample from the list items as additional cues did not have the expected positive effect on the recall of the remaining list items as one would have expected based on the notion that subjects use interitem associations during recall. SAM's ability to generate the part-list cuing effect was rather surprising since it ran counter to the then standard interpretation of that effect in terms of inhibitory factors. Subsequent experiments (reported in Raaijmakers and Phaf, 1999) demonstrated the viability of SAM's account of the part-list cuing effect.

SAM assumes that recall and recognition involve the same basic process of activating information. However, when a specific item X is tested for recognition, the response is not based on the retrieval of information from just the trace corresponding to X (although there is no principled reason why it could not be) but on the overall activation of the memory system induced by the retrieval cues. The overall activation is used as the familiarity measure in the

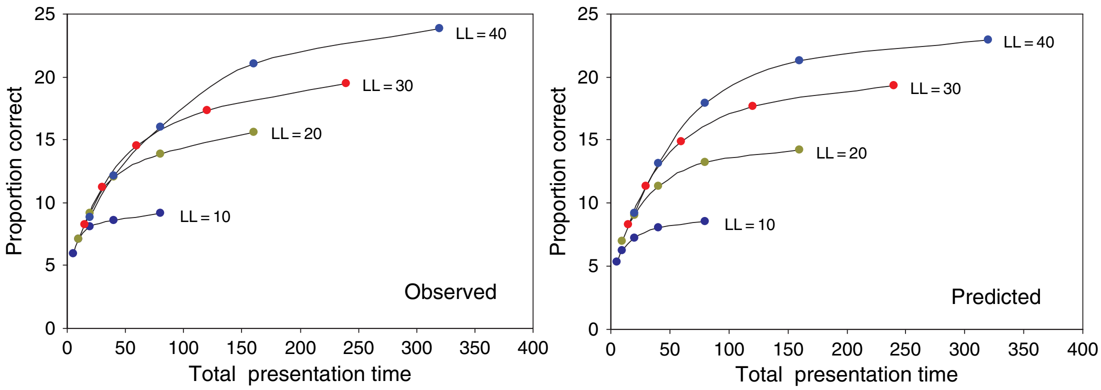


**Figure 3** Observed (left panel, Roberts WA (1972) Free recall of word lists varying in length and rate of presentation: A test of total-time hypotheses. *J. Exp. Psychol.* 92: 365–372) and predicted (right panel) mean number of correct recalls in free recall as a function of presentation time and list length (LL). Predictions are based on the SAM model with parameter values as given in Raaijmakers JGW and Shiffrin RM (1980) SAM: A theory of probabilistic search of associative memory. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory*, vol. 14, pp. 207–262. New York: Academic Press.

standard signal detection model for recognition. This approach to recognition is termed a global familiarity model, in contrast to local familiarity models that are based on the familiarity or activation of the target trace. The global familiarity model is currently the most popular approach to modeling recognition and is used in a variety of models other than SAM (e.g., TODAM, MINERVA2, REM). One obvious advantage of the global familiarity approach is that it provides a simple way to deal with false alarms, the recognition of nonlist items (the distractor items), without having to make any additional assumptions. In the SAM recognition model developed by Gillund and Shiffrin (1984), the global familiarity measure is simply the overall activation in response to the retrieval cues used, i.e., $\sum A(k)$, with $A(k)$ as in eqn [16].

In the SAM model, the role of context cues in episodic memory retrieval is emphasized. Many experiments have shown that testing in a context that is different from the context at the time of encoding leads to a decrease in performance (especially in free recall tasks) compared to testing in the same context. This holds both for changes in the environmental context (e.g., Godden and Baddeley, 1975; Smith, 1979; Grant et al., 1998) and changes in the internal state or context (Eich et al., 1975; Eich, 1980). Mensink and Raaijmakers (1988, 1989) extended this notion to within-session changes in context. They assumed that within an experimental session there are gradual changes in context and that the context that gets stored in a trace is a selection from the currently available context elements. The model that they developed was adapted from Stimulus Sampling Theory (Estes, 1955) and assumed that there was a random fluctuation between a set of available or current context elements and a set of (temporarily) unavailable context elements. Mensink and Raaijmakers (1988) showed how such a notion of context fluctuation in combination with the SAM model for cued recall could account for many of the traditional results in the area of interference and forgetting. Using the same basic model, Raaijmakers (2003) showed that it could also account for standard spacing effects. A related analysis of contextual fluctuation processes as well as an application to free recall was developed by Howard and Kahana (1999; see also Kahana, 1996). Whereas in the original Raaijmakers and Shiffrin (1981b) analysis of free recall, a constant context was assumed during presentation and testing of a single list, Howard and Kahana (1999) made the reasonable assumption that context varies even within a single list and that upon retrieval of a specific trace not just the item information would be retrieved, but also the stored context information. They showed how such a model could account for a number of detailed aspects of recall processes.

Nelson et al. (1998) developed a model (PIER2) related to SAM that they showed could successfully explain a large number of findings on the effects of extralist cues on recall. In these experiments, a list of items is studied; at test, the subjects are given a cue and they are told that the cue item is meaningfully related to one of the list items. The basic idea of PIER2 is that during encoding of a list of words, explicit as well as implicit representations (traces) are formed. The implicit representation is an automatic by-product of the comprehension process. Extralist cued recall may result from retrieving either the explicit or the implicit representation (or both). The PIER2 model focuses on the contribution to recall resulting from the implicit representation. It assumes that during encoding the study or target item as well as its associates are activated and that the activation strengths of both the target item and the associates are a function of their interconnectedness. At the time of testing, when the extralist cue is presented, a sampling function similar to that of SAM is used in which the probability of sampling the target item is proportional to the relative cue-to-target activation strength, relative to the strengths of the connections of the cue to its other associates and the strengths of the connections of the target to its other associates. Thus, the more unique the cue-to-target association (both at the cue side and at the target side) the higher the probability of sampling the (implicit) target representation. Using this sampling model, Nelson et al. (1998) showed that it successfully accounted for many results from previous experiments on extralist cuing.

Even though the SAM model has been quite successful in explaining a large variety of experimental results, the model in its original form fails to account for the list-strength effect (or rather the lack of it) and a number of other results in recognition (see Shiffrin et al., 1990). It soon became clear that in order to be able to explain these results, it would have to be assumed that the extent to which a trace is activated by an unrelated item cue should decrease as the number of features stored in that trace is increased (i.e., as the trace gets stronger). In SAM and most other models, it was assumed that the associative strength was a function of the number of overlapping elements, hence it should either stay the same or increase with the number of features stored.

A solution to this problem was found by adopting a so-called Bayesian or rational approach. In this type of approach (Shiffrin and Steyvers, 1997; McClelland and Chappell, 1998), it is assumed that the system, when confronted with an item that has to be accepted or rejected on a recognition test, makes an optimal decision based on the information that is stored in memory and knowledge of the rules that govern storage of information in memory. In the next section, we will discuss the REM model developed by Shiffrin and Steyvers (1997) as an example of this approach. A similar, independently developed model was presented by McClelland and Chappell (1998). Both of these models are based on the notion of differentiation, i.e., as an item gets stored better, it also becomes easier to differentiate from other items and will less likely be activated by cues representing other items. Although the models are quite similar in spirit (and would be considered equivalent on a purely verbal level), Criss and McClelland (2006) show that the two models are in fact not equivalent and will make different predictions for specific experiments (e.g., associative recognition). However, this analysis is beyond the scope of the present chapter.

### 2.25.3.2 The REM Model

As mentioned before, the REM model (Retrieving Effectively from Memory) is based on the assumption that the memory system behaves as an optimal decision-making system. On a simple recognition test, old and new items are presented and the subject has to decide whether the test item is old or new. REM assumes that the stored memory traces consist of samples of features from the studied items. Features may be stored correctly or incorrectly but as the study time increases, more features will be stored correctly. It is assumed that at test the system matches the features of the test item to each of the traces in memory. For a test item that was indeed on the list, there will of course be a relatively high number of matches and not many mismatches for the trace corresponding to that item. For all other traces (corresponding to the other items on the list) there will be more mismatches. For a distractor test item, all traces will have a relatively high number of mismatches and relatively few matches (since none of these traces corresponds to the test item). Hence, the number of matching and mismatching features gives information about whether the test item was on the list.

It is assumed that the system evaluates the evidence according to standard rules of probability theory and makes an optimal choice based on the available evidence. More specifically, the system chooses whichever response has the higher probability given the observed feature matches and mismatches in all the memory traces. Mathematically, the decision criterion is given by the posterior odds ratio, which according to Bayes' rule may be written as the product of the prior odds and the likelihood ratio:

$$\Phi = \frac{P(old|data)}{P(new|data)} = \frac{P(old)}{P(new)} \times \frac{P(data|old)}{P(data|new)} \qquad [20]$$

It can be shown that in REM, the likelihood ratio is given by the average likelihood ratio for the individual list traces (assume L episodic images are compared to the test probe):

$$\Phi = \frac{1}{L}\sum_j \frac{P(D_j/old)}{P(D_j/new)} = \frac{1}{L}\sum_j \lambda_j \qquad [21]$$

Hence, an old response would be given if $\Phi > 1$. An interesting result from this analysis is that the decision rule turns out to be an example of the global familiarity approach to recognition memory. There are, however, two major differences between the REM and the SAM models for recognition. One is that in SAM the response criterion is basically arbitrary, whereas in REM there is a natural criterion corresponding to a likelihood of 1.0. The other difference is that in REM the activation value $\lambda_j$ may be shown to be a function of both the number of matching and nonmatching features. For a simple version in which we simply count the number of matching and mismatching features, disregarding the exact value of the features (i.e., whether it is a very common or not so common value), it may be shown that the contribution to the overall likelihood for item $j$ is given by:

$$\lambda_j = \left(\frac{\alpha}{\beta}\right)^{m_j}\left(\frac{1-\alpha}{1-\beta}\right)^{q_j} \qquad [22]$$

where $\alpha$ is the probability of a match given storage for the correct trace, $\beta$ is the probability of a match given storage for an incorrect trace ($\alpha$ must obviously be larger than $\beta$), and $m_j$ and $q_j$ are the number of matches and mismatches, respectively, for trace $j$. Thus, the higher the number of matching features, the higher the likelihood, and the higher the number of mismatching features, the lower the likelihood. Earlier we mentioned the need to include information regarding the mismatching features in determining the activation of a trace in order to be able to account for list-strength effects. List-strength effects may be shown by comparing mixed lists composed of both strong and weak items, with pure lists consisting of only strong or only weak items. If there is a list-strength effect, the performance on the weak items in the pure weak list should be better than that on the weak items in the mixed list, and the performance on the strong items should be worse in the pure strong list compared to the mixed list. As shown in Figure 4 (these results were obtained using a simulation program developed by David Huber), the REM model indeed predicts no decrease in recognition performance due to increasing strength of the other list items, although it does predict a decrease as a function of an increase in the number of other list items.

Equation [21] also suggests a similarity between REM and SAM in that the likelihood ratio for a particular trace in REM seems to play a similar role as the activation values in SAM. This suggests that it might be possible to generalize REM to recall paradigms by substituting the likelihood ratios for the activation values. This approach has the desirable feature that most, if not all, of the SAM recall predictions hold for REM as well. Diller et al. (2001) showed that this indeed produces a viable model for

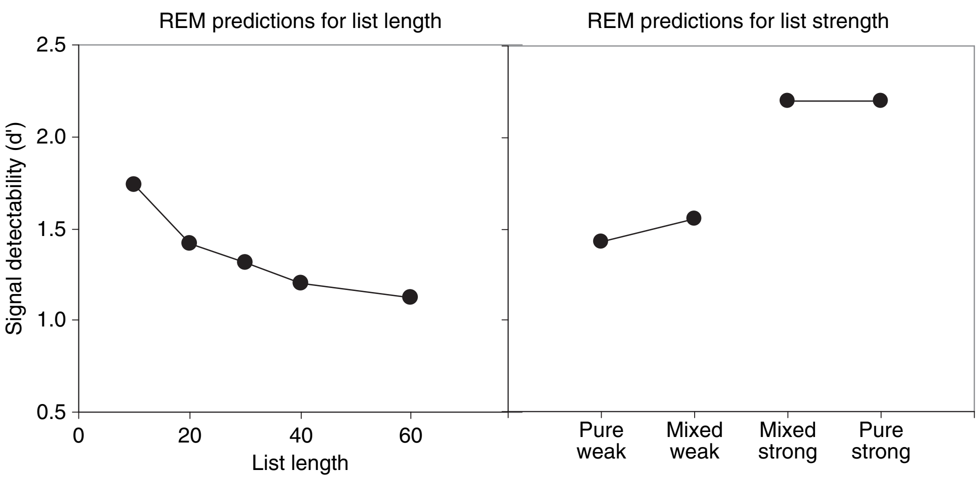


**Figure 4** Predicted values for signal detectability (d′) as a function of list length (left panel) and list strength (right panel) according to the REM model (parameter values: g = 0.4, c = 0.7, u = 0.05; see Shiffrin RM and Steyvers M (1997) A model for recognition memory: REM: Retrieving effectively from memory. *Psychon. Bull. Rev.* 4: 145–166).

recall provided that one raises the likelihood ratios to a constant power. Thus, they defined the probability of sampling trace $i$ as

$$P_S(I_i) = \frac{\lambda_i^\gamma}{\sum \lambda_k^\gamma} \qquad [23]$$

Soon after the REM model for recognition was developed, it was realized that it might be fruitfully generalized to other domains, in particular semantic and implicit memory. In this more general version of REM, it is assumed that when an item is encountered, (a sample of) its features are stored in an episodic trace but also in a lexical/semantic system. Hence, the lexical/semantic trace accumulates information from all prior occurrences and is updated each time the item is presented (see Schooler et al., 2001).

Schooler et al. (2001) developed a REM-based model to account for priming effects in perceptual identification. The model gave a successful account of the results obtained by Ratcliff and McKoon (1997) in the forced-choice identification paradigm. In these experiments, a word (e.g., LIED) is briefly flashed and then masked. The subject is then presented with two alternatives (e.g., LIED and DIED) and has to choose which of these two was the word that was flashed. The critical result in this paradigm is that there is priming (i.e., an increase in the probability of choosing an item that was previously presented on a study list) but only when the two alternatives at the test are perceptually similar (LIED, DIED), but not when they are perceptually dissimilar (e.g., LIED, SOFA). Schooler et al. showed that this pattern of results can be explained in REM by the assumption that a small number of context features are added to the lexical/semantic trace of an item as a result of the prior presentation. These additional context features will obviously have a high probability of matching the later test context, hence will increase (although by a small amount) the number of matching features for the trace corresponding to the primed alternative. The crucial aspect in the REM explanation is that for similar alternatives the outcome of the feature match will often be the same, hence only a relatively small number of perceptual features will be relevant for the decision to choose one or the other alternative. As a result, the additional matches provided by the context features will have a larger effect when the alternatives are perceptually similar than when they are dissimilar.

To see this more clearly, **Figure 5** shows the distributions for the number of critical features for

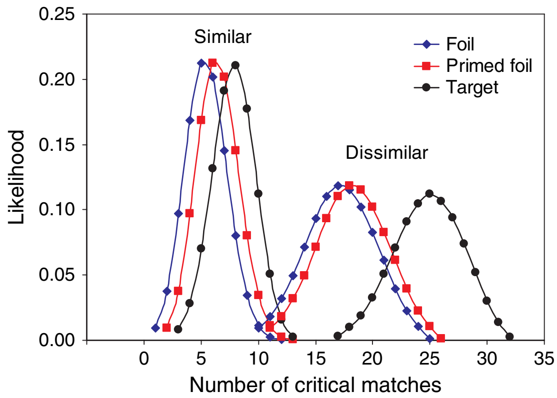


**Figure 5** Predicted likelihood distribution for the number of critical matches for similar and dissimilar choice alternatives according to the REM model of Schooler LJ, Shiffrin RM, and Raaijmakers JGW (2001) A Bayesian model for implicit effects in perceptual identification. *Psychol. Rev.* 108: 257–272.

each of the choice alternatives that match the flashed item. Critical features are features that potentially can make a difference between the two alternatives. Since there are fewer critical features that differentiate similar alternatives, the number of matching critical features will also be lower. Assume that the foil item was presented on the prior study list and that this results in just one additional match due to context overlap between study and test. As shown in **Figure 5**, this additional match will have a clear effect for the similar alternatives: There is much more overlap between the distributions, and hence the probability that the target has more matches compared to the foil will decrease quite a bit. For the dissimilar alternatives, the added match due to context has only a small effect on the probability of choosing the target (the probability of a correct response). Hence, the effect of prior study will be much larger for the similar alternatives compared to the dissimilar ones.

Wagenmakers et al. (2004) presented an application of REM to standard lexical decision tasks in which it was assumed that a lexical decision is based on the evaluation of the likelihood that the presented item corresponds to a word in the lexical system versus a nonword (just as a recognition decision is based on the evaluation that the test item corresponds to an item stored in the episodic system). There is a time-dependent encoding process such that as encoding time increases more and more probe features become available. The likelihood at time $t$ is determined from the features available at that time. The model was evaluated using signal-to-respond tasks and gave a good account for the effects of several major factors such as word frequency, repetition priming, and nonword lexicality.

Raaijmakers (2005) gives an outline of how the REM model may be extended to several other implicit and semantic memory paradigms such as associative priming, semantic categorization tasks, and associative repetition priming. A common feature of all of these applications is that the lexical/semantic system is assumed to be a much more flexible system than in many traditional accounts and that lexical/semantic traces do contain contextual features and hence are sensitive to recent episodes in which the item was presented.

## 2.25.4 Neural Network Approaches

All the approaches that I have discussed thus far do not make specific reference to how the processes that are postulated are actually implemented in the brain. The models in this section on the other hand take the analogy to neural processes in the brain as their starting point. It is assumed that information is distributed over sets of nodes in a neural network rather than as separate traces as in the models discussed thus far. Information is coded not in separate nodes or individual links but in the pattern of strengths over a large number of links or nodes. Hence, each individual node or link participates in the representation of many items or associations. Whenever a specific cue item is presented, the corresponding input nodes are activated and this activation is propagated through a network of links, leading to a specific pattern of activation at the output nodes and this pattern defines the output or the item retrieved from memory. The crucial property of these models (and the one that initially attracted the most attention) is that they provided a mechanistic account of the critical property that distinguishes human memory from other types of memory (such as hard disks), namely its associative character. That is, associative memory systems have the property that if the association *A-B* is stored, presentation of the cue *A* will automatically retrieve *B* without the need to know where *B* (or *A-B*) was stored. In models such as ACT and SAM, this property is assumed, but in neural network models, a computational account is given that generates the associative property, rather than assuming it.

To illustrate this, consider a very simple neural network model in which there is an input layer of neurons and an output layer of neurons and in which each input neuron is connected to each output neuron (e.g., Anderson et al., 1977). Items are represented by vectors, i.e., a series of activation values over the input or output neurons. In order to store the association *A-B*, the connections between the input *A* and the output *B* have to be modified in such a way that presenting *A* at the input side will produce *B* at the output side. This may be accomplished by modifying the connections between the *A* and *B* vectors in such a way that if the *i*-th value of *A* and the *j*-th value of *B* are both high, the connection is made stronger. More generally, if $\mathbf{f_i}$ is the feature vector for item *A* and $\mathbf{g_i}$ is the feature vector for item *B*, then the connections between the input nodes and the output nodes are increased by an amount equal to the product of the feature values. Using vector notation, this is equivalent to the assumption that the changes in the synaptic strengths are modified according to the matrix $\mathbf{M}_i$:

$$\mathbf{M}_i = \mathbf{f}_i\mathbf{g}_i{}' \qquad [24]$$

Thus, if a list of such pairs is studied, the strengths are modified according to the matrix $\mathbf{M}$ with $\mathbf{M} = \sum \mathbf{M}_i$. Presenting an item as a cue to such a system amounts to postmultiplying the matrix $\mathbf{M}$ with the item vector. It is relatively easy to show that in the ideal case where all items vectors are uncorrelated and of unit length, such a model will show the associative property, i.e., on presentation of the item *A* ($\mathbf{f_i}$) the system will generate the associated item *B* ($\mathbf{g_i}$):

$$\mathbf{Mf_i} = \sum \mathbf{M_j f_i} = \sum_{j \neq i} \left(\mathbf{g_j f_j}'\right)\mathbf{f_i} + \left(\mathbf{g_i f_i}'\right)\mathbf{f_i} = \mathbf{g_i} \qquad [25]$$

The example given above is the simplest model of this kind and much more complicated models or networks have been proposed. All of these models, however, share the basic assumption that the associative information is encoded in the links or connections between the neurons. Item information is represented by the pattern or distribution of the activation values at the input and output layers. Note that the same nodes are used to represent all the items: The information is distributed over many nodes. Such models are therefore often called connectionist or distributed memory models. They may contain several layers of neurons with connections between successive layers (see Ackley et al., 1985; Rumelhart et al., 1986). Since the associative property that all of these models share may also be expressed as implying that the model learns to predict the output vector given a specific input vector, it is not surprising that connectionist models have been developed not just to simulate human memory but also to compute any type of predictive relation between a specific input and specific output (i.e., associating a spoken output or phonemes based on the written input text, as in the NETtalk model; Sejnowski and Rosenberg, 1987). These more complex variants do not learn the associations in a single step (as in the simple model described earlier), but require several iterations in which the links between the nodes in the network are gradually changed. Basically what these models do is perform a kind of nonlinear regression using a least-squares fitting procedure to predict the output values given the input values.

Although these models have been quite successful in other domains, their success as a general framework for human memory is more limited. There are a number of features of these models that are problematic when they are used as models for episodic memory.

The most basic problem is known as catastrophic forgetting (McCloskey and Cohen, 1989; Ratcliff, 1990). This property is related to the fact that these models focus on extracting generalized rules from a series of exemplars rather than on storing individual items. The issue is that distributed memory models tend to forget all previously learned information on learning a new set of items. This is most clearly shown in the application of the back-propagation model to a retroactive interference experiment in which two lists are learned in succession (see McCloskey and Cohen, 1989). After learning the second list, humans will show some forgetting for the first list but the forgetting is far from complete. A typical back-propagation model, however, will show complete forgetting of the first list and in fact learning of the second list only starts after the first list has been completely unlearned. Such drastic forgetting is quite different from what is observed in experiments with humans, hence the name catastrophic forgetting. The basic reason for this incorrect prediction is that all the information is contained in the strengths or weights of the links in the network, and since these weights are freely adjusted during second-list learning to optimize second-list performance, there is nothing that prevents the complete forgetting of the first list information. Similar problems for recognition memory performance were demonstrated by Ratcliff (1990), who also showed that the model fails to predict a positive effect of amount of learning on the $d'$ measure for recognition.

It should be noted that these problems are not inherent to distributed memory models but seem to be limited to those connectionist models that assume that learning an item involves an optimization of the weights given to the links in order to tune the network to the information that it is currently being trained on. Murdock (1982, 1993), for example, developed a general framework for memory based on a distributed representation (TODAM, Theory of Distributed Associative Memory) in which item and associative information are added to a single memory vector (similar to the simple vector model described earlier) without any additional tuning. In TODAM, item information is simply added to the trace, while associative information (say the association A–B) is modeled by computing a vector that corresponds to the convolution of the vectors representing **A** and **B** (denoted as $\mathbf{A}^*\mathbf{B}$). Murdock showed that in such a model when A is presented as a cue, B (or at least a noisy version of the **B** vector) may be retrieved by computing the correlation of the **A** vector with the memory vector. TODAM does not suffer from the catastrophic forgetting problem presumably because a second list adds information (and hence noise) to the memory vector but does not destroy the information from the first list.

In order to prevent these problems in connectionist models, changes have to made to the basic structure of such models. One solution is to eliminate the strong version of the distributed memory assumption. For example, it might be assumed that there are a large number of nodes or connections and that learning a particular item or an association uses only a small proportion of these (e.g., so-called sparse distributed networks). Alternatively, it might be assumed that information concerning first-list learning continues to be stored in memory for a relatively long period after the learning of that list (a version of consolidation theory). In this way, the two lists become one list and a compromise is found between first- and second-list performance (see McClelland et al., 1995, for an ingenious version of this approach). Yet another approach is to relax the assumption that specific items are stored in a distributed manner, for example, competitive learning models using a winner-take-all principle in which retrieval results in a single unit are activated (retrieved) or a novelty-detection assumption that enables the system to allocate new items to units not already used to represent other items (e.g. Murre, 1992).

There are other problems that are not as easy to remediate in distributed memory models. For example, Shiffrin et al. (1990) showed that many network models have problems simultaneously predicting the presence of list-length effects and the absence of list-strength effects in recognition memory. Extra items harm performance by changing weights, but strengthening other items also changes the weights and should therefore cause similar harm. As yet, there is no clear solution for this problem within the framework of distributed memory models.

Despite these problems, neural network models continue to have a major influence on memory theories. These models have the advantage of a much closer link to neurobiological approaches and, more importantly, they still provide the only mechanistic explanation for the associative memory property. A nice example of a modern neural network model is the Complementary Learning Systems (CLS) approach proposed by McClelland et al. (1995) and further elaborated by O'Reilly and Rudy (2001) and Norman and O'Reilly (2003). The CLS approach is based on the realization that the memory system must combine two seemingly incompatible functions: Storage of episodic memories and integration of information to enable generalization. The first requires storage of specific, separated traces, whereas the second requires overlapping representations. The phenomenon of catastrophic forgetting shows that standard distributed representations are not a suitable model for episodic memory, although they do allow generalization. The solution in the CLS approach is to assume two separate but interactive systems: A rapidly changing system (assumed to be located in the hippocampal system) and a more slowly changing system (assumed to be cortical or neocortical). The hippocampal system is assumed to employ sparse compressed representations to minimize interference between traces, while the cortical system uses more standard distributed (overlapping) representations. It is assumed that there is a slow consolidation process that transfers information from the hippocampal to the cortical system. During recall, a cue will activate a corresponding pattern in the cortical system and if this pattern is sufficiently close to a stored hippocampal trace, the hippocampal system will settle on that trace, which then sends back activation to the cortical system, leading to the reinstatement of the original event pattern. Catastrophic interference in the neocortical system is avoided by a kind of consolidation process in which storage of new information is interleaved with renewed activation of older information.

McClelland et al. (1995) show how such a model may be used to explain a variety of findings from both human and animal experiments. For example, the fact that amnesic patients are unable to recall recent episodic experiences yet are able to recall older memories and do show implicit memory is attributed to a defect in the hippocampal system coupled with an intact cortical memory system. Norman and O'Reilly (2003) presented simulation results showing that the CLS model gives a good account of recognition memory. For example, the model may predict little or no list-strength effect in recognition if the recognition decision is mostly based on familiarity stemming from the cortical system (rather than on recall based on the hippocampal system). It is not clear, however, how the CLS model would handle both the absence of list-strength effects and the presence of list-length effects in recognition (see Norman and O'Reilly, 2003: 632).

However, even though these newer versions of connectionist modeling provide a solution for a number of the problems that plagued older connectionist models, there are several remaining issues. One is that it is not always clear which aspects of the model are responsible for a specific prediction. Although this is also a concern with other general modeling approaches, the issue is particularly relevant for these models. When a model successfully predicts a specific phenomenon, one also wants to know which aspects of the model are crucial for that prediction and which elements of the model (or the simulation) are incidental. For example, the model may employ a specific learning rule to optimize the weights or a specific equation for the decay of activation values. When one tries to understand why the model predicts the phenomenon, it is important to know whether it would still predict the phenomenon when a different learning rule or a different equation for decay (or perhaps no decay at all) is assumed. Thus, the ability to simulate a specific result does not yet mean that one has an explanation for that phenomenon (see also McCloskey, 1991; see O'Reilly and Farah, 1999, for a contrasting point of view). In many cases (for example, the prediction of the part-list cuing effect in SAM, see Raaijmakers and Phaf, 1999), a substantial amount of work is involved in figuring out why the model makes the prediction, but it is the additional work that ultimately leads to a model-independent explanation of the phenomenon. Such analyses are especially needed when it is difficult for other researchers to run the required model simulations.

## 2.25.5 Models for Serial Order Memory

In this section, I will discuss a number of models that have been proposed to account for memory for serial order information. Such models focus on explaining memory for item and order information in relatively short lists. For example, subjects might be presented with one or more lists of five items and then be given a test in which the items have to be recalled in the correct order, or they might be given the items at test (in a different order) and then asked to provide the correct order of presentation. The empirical evidence for (or against) these models is discussed by Healy and Bonk (*See* Chapter 2.05). We will restrict our discussion to the mathematical formulations that have been used.

A classic approach in this area is Estes' perturbation model (Estes, 1972). In this model, it was assumed that during study, items are associated or linked to their serial positions. However, during the retention interval, the item may shift (perturb) to a neighboring position. If one assumes that movements to an earlier or to a later position are equally likely, then the probability that an item occupies a particular position $n$ at a given time $t$ is given by the following difference equation:

$$P_{n,t} = (1-\theta)P_{n,t-1} + (\theta/2)P_{n-1,t-1} + (\theta/2)P_{n+1,t-1} \quad [26a]$$

For the endpoints we have a slightly different equation:

$$P_{1,t} = (1-\theta/2)P_{1,t-1} + (\theta/2)P_{2,t-1} \quad [26b]$$

for the first position and similarly for the final list position.

These relatively simple equations allow one to calculate the probability distribution for each item on the list. The model predicts better recall for items in the beginning and end positions than for items in the middle of the list since these items will have had less opportunity to perturb. Nairne (1992) obtained data for five-item lists at retention intervals of 30 s, 4 h, and 24 h and showed that the perturbation model gave a good quantitative account of the data. Note that in order to apply the model, one needs to estimate not just the perturbation parameter $\theta$ but also the number of cycles of perturbation (the number of times that eqn [26] is applied). It is easy to see that the model can also handle a number of other findings such as a higher accuracy if there are longer intervals between successive items (longer intervals will lead to less perturbation).

The perturbation model is an example of a bin model in which items are placed in or linked to serial positions rather than to one another. That is, a common view of serial order memory is that order memory is derived from item-to-item associations (the temporal order of a string such as ABCD is remembered through the pairwise associations A-B, B-C etc). What the perturbation model shows is that this type of view is not a necessary one and that an alternative view in which order information is not based on item-to-item associations but on memory for positional information can also give a good account of the data. However, a number of problems have been mentioned in the literature regarding such bin models, the most important one being that these models give no account of the recall of item information (cuing with a specific position automatically leads to recall of the linked item). In addition, it seems to be assumed that at test, the successive bins are always searched in the correct order (a rather strong assumption in the case of somewhat longer lists).

A prime example of a chaining model for serial order memory is the model proposed by Lewandowsky and Murdock (1989). Their model was based on the TODAM framework for memory, one of the distributed memory models discussed earlier. In this application of TODAM, it was assumed that recall starts by using a context cue to generate the first item, and then this item is used as a cue to generate the second item, and so on. A key problem for any type of chaining model is how to proceed if at a particular point no item is recalled. In TODAM, even though the retrieved vector may not enable the recall of a given item (the process of cleaning up the output vector via comparison to a lexicon may not succeed), the retrieved vector may still be used as a further cue.

Finally, Brown et al. (2000) developed a model for serial memory (termed OSCAR) that relies on contextual information to generate temporal information. In their model, context is represented as a series of oscillators that produce a dynamically changing state. The output from the oscillators forms a context vector. The model assumes that the overall context is made up of several such context vectors. During presentation of the list of items, each item vector is associated with the state of each context vector at the time of presentation. Thus, item 1 is associated to context vector 1 at time 1, context vector 2 at time 1, etc. Similarly, item 2 is associated to context vector 1 at time 2, context vector 2 at time 2, etc. All of the item–context associations for each context vector are stored in an association matrix, similar to eqn [24]. At recall, the initial state of the context vectors is reinstated and these are then used to regenerate the context vectors at the following times. To recall the item that was presented at time *m*, context vector 1 at time *m* is multiplied with the memory matrix corresponding to context vector 1 (see eqn [25]), which produces an approximation to item *m*. Similarly, the context vector 2 is used in the same way, also leading to an approximation to item *m*, and so on for all context vectors. Finally, the item in a separately stored vocabulary of items that provides the best overall match to the various approximations of item *m* is then produced as the response. Thus, in this model, recall of a series of ordered items is based on the recall of gradually changing contexts that provide the temporal information for order memory. The OSCAR model is an example of a model for order recall that is based not on interitem associations but on the retrieval of temporal information that is specific to the time that a particular item was studied. The model provides a mechanism for how the system recalls the various contexts as well as the items that were presented. What is not clear, however, is how essential the specific formalization that Brown et al. (2000) used is for the predictions generated by OSCAR (e.g., which properties of the context vectors are essential, and are oscillators really required to enable the model to make these predictions).

## 2.25.6 Concluding Remarks

In the previous sections, I have presented an overview of several global frameworks for human memory. In this section, I return to the question raised in the introduction about what makes such models useful for understanding human memory processes.

Perhaps the most important advantage of having a formal model is that it makes it possible to prove that a specific argument or verbal explanation of a phenomenon is indeed valid (or the reverse: Show that it is not a valid argument). Many striking examples of such results may be found in the literature, for example:

- Batchelder's (1975) demonstration that the results from experiments on all-or-none learning could not be explained as being due to selection effects due to individual differences, as was thought by many proponents of theories in which learning was assumed to be more gradual.
- The demonstration by Hintzman and Ludlam (1980) that a purely exemplar-based classification model (MINERVA) could explain the finding that prototypical information seemed to be forgotten slower than the instances themselves. This finding had been generally interpreted as implying the existence of a prototype representation that was assumed to show a slower decay than the instance representations. The MINERVA model, however, did not contain any prototype representation and yet predicted the observed pattern of forgetting.
- The analysis of the part-list cuing paradigm using the SAM model (Raaijmakers and Shiffrin, 1981b) that showed that the lack of a positive cuing effect was entirely compatible with a model that was strongly based on the use of interitem associations. This analysis led to a new explanation for part-list cuing effects that we would not have thought of prior to running the analyses.

There are many such examples in the literature, and they do not necessarily have to be positive (in the sense of providing a new or alternative explanation). In some cases, computational analyses may show that a model fails to predict a finding that one would have intuitively thought that it should be able to predict. For example, the demonstration by McCloskey and Cohen (1989) of the catastrophic forgetting phenomenon shown by typical connectionist models had a big impact on the field. Similarly, Murdock and Lamon's (1988) demonstration that simple connectionist models failed to predict improved recognition performance with an increasing number of presentations was also initially met with disbelief.

What these examples show is that formal modeling may help to sharpen theoretical analyses by showing which results directly follow from a specific set of assumptions, which results cannot be predicted by the model, and which results may be predicted by the model but only under specific conditions (e.g., specific sets of parameter values). However, in order to be able to draw such conclusions, the modeler should not be content just to show that his or her model can predict the results of a particular set of experiments. This should be considered step one in the analyses and should be followed by additional analyses to determine the robustness of the prediction (does it vary in a qualitative sense when parameters are set to different values) as well as analyses to determine which aspects (assumptions) of the model are really crucial for the prediction. The latter aspect is often left out but is in my view the essence of the modeling approach: Models should not be used as black boxes that in some mysterious way generate a specific pattern of data, but should preferably be used as analytical tools to assist the theoretical analysis of those data (what does it tell us about human memory processes?).

The latter point is related to the view that a model that is applied to a specific experimental paradigm is really a combination of (1) a set of core theoretical assumptions (the general theory), (2) a number of auxiliary assumptions related to the implementation of the model and specific computational aspects (e.g., an assumption that each trial adds the same amount of strength to a trace, or the specific learning rule used in a connectionist model), and (3) a set of task-specific assumptions (say a particular rehearsal strategy that is assumed or the rules that are used in generating an overt response based on the retrieved information). In this view, the ultimate goal of mathematical modeling is not simply fitting a set of data but to provide insight into the basic structure and processes in a particular domain. As such, there is no real difference with non-mathematical approaches. The basic advantage of the modeling approach is that it provides an analytical tool that can be used to experiment in a way that is not possible with verbally stated theories.

Viewed in this way, the progression of simple models that could only be applied to a single type of experiment to the more general approaches that we have discussed in this chapter is a major step toward a more coherent and comprehensive theory of learning and memory processes.

## References


Ackley DH, Hinton GE, and Sejnowski TJ (1985) A learning algorithm for Boltzmann machines. *Cogn. Sci.* 9: 147–169.

Anderson JA, Silverstein JW, Ritz SA, and Jones RS (1977) Distinctive features, categorical perception, and probability learning: Some applications of a neural model. *Psychol. Rev.* 84: 413–451.

Anderson JR (1976) *Language, Memory, and Thought*. Hillsdale, NJ: Erlbaum.

Anderson JR (1981) Interference: The relationship between response latency and response accuracy. *J. Exp. Psychol. Hum. Learn.* 7: 326–343.

Anderson JR (1983a) *The Architecture of Cognition*. Cambridge, MA: Harvard University Press.

Anderson JR (1983b) A spreading activation theory of memory. *J. Verb. Learn. Verb. Behav.* 22: 261–295.

Anderson JR and Schooler LJ (1991) Reflections of the environment in memory. *Psychol. Sci.* 2: 396–408.

Anderson JR, Bothell D, Lebiere C, and Matessa M (1998) An integrated theory of list memory. *J. Mem. Lang.* 38: 341–380.

Anderson JR, Qin Y, Sohn M-H, Stenger VA, and Carter CS (2003) An information-processing model of the BOLD response in symbol manipulation tasks. *Psychon. Bull. Rev.* 10: 241–261.

Anderson JR, Qin Y, Stenger VA, and Carter CS (2004) The relationship of three cortical regions to an information-processing model. *J. Cogn. Neurosci.* 16: 637–653.

Anderson JR, Albert MV, and Fincham JM (2005) Tracing problem solving in real time: fMRI analysis of the subject-paced Tower of Hanoi. *J. Cogn. Neurosci.* 17: 1261–1274.

Atkinson RC and Crothers EJ (1964) A comparison of paired associate learning models having different acquisition and retention axioms. *J. Math. Psychol.* 1: 285–315.

Atkinson RC and Juola JF (1974) Search and decision processes in recognition memory. In: Krantz DH, Atkinson RC, Luce RD, and Suppes P (eds.) *Contemporary Developments in Mathematical Psychology, Vol. 1: Learning, Memory, and Thinking*, pp. 242–293. San Francisco: Freeman.

Atkinson RC and Shiffrin RM (1968) Human memory: A proposed system and its control processes. In: Spence KW and Spence JT (eds.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 2, pp. 89–105. San Diego: Academic Press.

Batchelder WH (1970) An all-or-none theory for learning on both the paired-associate and concept levels. *J. Math. Psychol.* 7: 97–117.

Batchelder WH (1975) Individual differences and the all-or-none vs incremental learning controversy. *J. Math. Psychol.* 12: 53–74.

Bjork RA (1966) Learning and short-term retention of paired associates in relation to specific sequences of interpresentation intervals. Technical Report no. 106. Institute for Mathematical Studies in Social Sciences, Stanford University, Palo Alto, CA.

Bower GH (1961) Application of a model to paired-associate learning. *Psychometrika* 26: 255–280.

Brown GDA, Preece T, and Hulme C (2000) Oscillator-based memory for serial order. *Psychol. Rev.* 107: 127–181.

Collins AM and Loftus EF (1975) A spreading-activation theory of semantic processing. *Psychol. Rev.* 82: 407–428.

Craik FIM and Lockhart RS (1972) Levels of processing: A framework for memory research. *J. Verb. Learn. Verb. Behav.* 11: 671–684.

Criss AH and McClelland JL (2006) Differentiating the differentiation models: A comparison of the retrieving effectively from memory model (REM) and the subjective likelihood model (SLiM). *J. Mem. Lang.* 55: 447–460.

Diller DE, Nobel PA, and Shiffrin RM (2001) An ARC-REM model for accuracy and response time in recognition and cued recall. *J. Exp. Psychol. Learn.* 27: 414–435.

Eich JE (1980) The cue-dependent nature of state-dependent retrieval. *Mem. Cognit.* 8: 157–173.

Eich JE, Weingartner H., Stillman RC, and Gillin JC (1975) State-dependent accessibility of retrieval cues in the retention of a categorized list. *J. Verb. Learn. Verb. Behav.* 14: 408–417.

Estes WK (1955) Statistical theory of spontaneous recovery and regression. *Psychol. Rev.* 62: 145–154.

Estes WK (1972) An associative basis for coding and organization in memory. In: Melton AW and Martin E (eds.) *Coding Processes in Human Memory*, pp. 161–190. Washington, DC: Wiley.

Gillund G and Shiffrin RM (1984) A retrieval model for both recognition and recall. *Psychol. Rev.* 91: 1–67.

Godden DR and Baddeley AD (1975) Context-dependent memory in two natural environments: On land and underwater. *Br. J. Psychol.* 66: 325–331.

Grant HM, Bredahl LC, Clay J, et al. (1998) Context-dependent memory for meaningful material: Information for students. *Appl. Cogn. Psychol.* 12: 617–623.

Greeno JG (1968) Identifiability and statistical properties of two-stage learning with no successes in the initial stage. *Psychometrika* 33: 173–215.

Greeno JG (1974) Representation of learning as discrete transition in a finite state space. In: Krantz DH, Atkinson RC,

Luce RD, and Suppes P (eds.) *Contemporary Developments in Mathematical Psychology, Vol. 1: Learning, Memory, and Thinking*, pp. 1–24. San Francisco: Freeman.
Greeno JG and Scandura JM (1966) All-or-none transfer based on verbally mediated concepts. *J. Math. Psychol.* 3: 388–411.
Hintzman DL and Ludlam G (1980) Differential forgetting of prototypes and old instances: Simulation by an exemplar-based classification model. *Mem. Cognit.* 8: 378–382.
Howard MW and Kahana MJ (1999) Contextual variability and serial position effects in free recall. *J. Exp. Psychol. Learn.* 25: 923–941.
Humphreys M and Greeno JG (1970) Interpretation of the two-stage analysis of paired-associate memorizing. *J. Math. Psychol.* 7: 275–292.
James CT and Greeno JG (1970) Effect of A-B overtraining in A-BR. *J. Exp. Psychol.* 83: 107–111.
Kahana MJ (1996) Associative retrieval processes in free recall. *Mem. Cognit.* 24: 103–109.
Lee MD (2004) A Bayesian analysis of retention functions. *J. Math. Psychol.* 48: 310–321.
Lewandowsky S and Murdock BB (1989) Memory for serial order. *Psychol. Rev.* 96: 25–57.
McClelland JL and Chappell M (1998) Familiarity breeds differentiation: A subjective-likelihood approach to the effects of experience in recognition memory. *Psychol. Rev.* 105: 724–760.
McClelland JL, McNaughton BL, and O'Reilly RC (1995) Why there are complementary learning systems in the hippocampus and neocortex: Insights from the successes and failures of connectionist models of learning and memory. *Psychol. Rev.* 102: 419–457.
McCloskey M (1990) Networks and theories: The place of connectionism in cognitive science. *Psychol. Sci.* 2: 387–395.
McCloskey M and Cohen NJ (1989) Catastrophic interference in connectionist networks: The sequential learning problem. In: Bower GH (ed.) *The Psychology of Learning and Motivation,* vol. 24, pp. 109–164. New York: Academic Press.
Mensink GJ and Raaijmakers JGW (1988) A model for interference and forgetting. *Psychol. Rev.* 95: 434–455.
Mensink GJM and Raaijmakers JGW (1989) A model of contextual fluctuation. *J. Math. Psychol.* 33: 172–186.
Murdock BB (1982) A theory for the storage and retrieval of item and associative information. *Psychol. Rev.* 89: 609–626.
Murdock BB (1993) TODAM2: A model for the storage and retrieval of item, associative, and serial-order information. *Psychol. Rev.* 100: 183–203.
Murdock B and Lamon M (1988) The replacement effect: Repeating some items while replacing others. *Mem. Cognit.* 16: 91–101.
Murre J (1992) *Learning and Categorization in Modular Neural Networks*. Hillsdale, NJ: Erlbaum.
Myung IJ and Pitt MA (2002) Model evaluation testing and selection. In: Lambert K and goldstone R (eds.) *The Handbook of Cognition*, pp. 422–436. London: Sage.
Nairne JS (1992) The loss of positional certainty in long-term memory. *Psychol. Sci.* 3: 199–202.
Nelson DL, McKinney VM, Gee NR, and Janczura GA (1998) Interpreting the influence of implicitly activated memories on recall and recognition. *Psychol. Rev.* 105: 299–324.
Norman KA and O'Reilly RC (2003) Modeling hippocampal and neocortical contributions to recognition memory: A complementary-learning-systems approach. *Psychol. Rev.* 110: 611–646.
O'Reilly RC and Farah MJ (1999) Simulation and explanation in neuropsychology and beyond. *Cogn. Neuropsychol.* 16: 49–72.
O'Reilly RC and Rudy JW (2001) Conjunctive representations in learning and memory: Principles of cortical and hippocampal function. *Psychol. Rev.* 108: 311–345.
Pavlik PI and Anderson JR (2005) Practice and forgetting effects on vocabulary memory: An activation-based model of the spacing effect. *Cogn. Sci.* 29: 559–586.
Polson PG (1972) A quantitative theory of the concept identification processes in the Hull paradigm. *J. Math. Psychol.* 9: 141–167.
Raaijmakers JGW (1979) *Retrieval from Long-Term Store: A General Theory and Mathematical Models.* PhD Thesis, University of Nijmegen, The Netherlands.
Raaijmakers JGW (1993) The story of the two-store model: Past criticisms, current status, and future directions. In: Meyer DE and Kornblum S (eds.) *Attention and Performance XIV: Synergies in Experimental Psychology, Artifical Intelligence, and Cognitive Neuroscience*, pp. 467–488. Cambridge, MA: MIT Press.
Raaijmakers JGW (2003) Spacing and repetition effects in human memory: Application of the SAM model. *Cogn. Sci.* 27: 431–452.
Raaijmakers JGW (2005) Modeling implicit and explicit memory. In: Izawa C and Ohta N (eds.) *Human Learning and Memory: Advances in Theory and Application*, pp. 85–105. Mahwah, NJ: Erlbaum.
Raaijmakers JGW and Phaf RH (1999) Part-list cuing revisited: A test of the SAM explanation. In: Izawa C (ed.) *On Memory: Evolution Progress and Reflection on the 30th Anniversary of the Atkinson-Shiffrin Model*, pp. 87–104. Mahwah, NJ: Erlbaum.
Raaijmakers JGW and Shiffrin RM (1980) SAM: A theory of probabilistic search of associative memory. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 14, pp. 207–262. New York: Academic Press.
Raaijmakers JGW and Shiffrin RM (1981a) Order effects in recall. In: Long JB and Baddeley AD (eds.) *Attention and Performance IX*, pp. 403–415. Hillsdale, NJ: Erlbaum.
Raaijmakers JGW and Shiffrin RM (1981b) Search of associative memory. *Psychol. Rev.* 88: 93–134.
Ratcliff R (1990) Connectionist models of recognition memory: Constraints imposed by learning and forgetting functions. *Psychol. Rev.* 97: 285–308.
Ratcliff R and McKoon G (1981) Does activation really spread? *Psychol. Rev.* 88: 454–457.
Ratcliff R and McKoon G (1997) A counter model for implicit priming in perceptual word identification. *Psychol. Rev.* 104: 319–343.
Roberts WA (1972) Free recall of word lists varying in length and rate of presentation: A test of total-time hypotheses. *J. Exp. Psychol.* 92: 365–372.
Rumelhart DE (1967) The effects of interpresentation intervals on performance in a continuous paired-associate task. Technical Report 16. Institute for Mathematical Studies in Social Sciences, Palo Alto, CA, Stanford University.
Rumelhart DE, Hinton GE, and Williams RJ (1986) Learning internal representations by error propagation. In: Rumelhart DE and McClelland JL (eds.) *Parallel Distributed Processing: Explorations in the Microstructures of Cognition, Vol. 1: Foundations*, pp. 318–362. Cambridge, MA: MIT Press.
Schooler LJ, Shiffrin RM, and Raaijmakers JGW (2001) A Bayesian model for implicit effects in perceptual identification. *Psychol. Rev.* 108: 257–272.
Sejnowski TJ and Rosenberg CR (1987) Parallel networks that learn to pronounce English text. *Complex Systems* 1: 145–168.
Shiffrin RM (1968) Search and retrieval processes in long-term memory. Technical Report 137. California: Institute for Mathematical Studies in the Social Sciences, Palo Alto, CA, Stanford University.
Shiffrin RM (1970) Memory search. In: Norman DA (ed.) *Models of Human Memory*, pp. 375–447. New York: Academic Press.

Shiffrin RM and Atkinson RC (1969) Storage and retrieval processes in long-term memory. *Psychol. Rev.* 76: 179–193.

Shiffrin RM and Steyvers M (1997) A model for recognition memory: REM: Retrieving effectively from memory. *Psychon. Bull. Rev.* 4: 145–166.

Shiffrin RM, Ratcliff R, and Clark S (1990) The list-strength effect: II. Theoretical mechanisms. *J. Exp. Psychol. Learn.* 16: 179–195.

Sirotin YB, Kimball DR, and Kahana MJ (2005) Going beyond a single list: Modeling the effects of prior experience on episodic free recall. *Psychon. Bull. Rev.* 12: 787–805.

Smith SM (1979) Remembering in and out of context. *J. Exp. Psychol. Hum. Learn.* 5: 460–471.

Underwood BJ and Schulz RW (1960) *Meaningfulness and Verbal Learning*. Chicago: Lippincott.

Wagenmakers EJM, Steyvers M, Raaijmakers JGW, Shiffrin RM, Van Rijn H, and Zeelenberg R (2004) A model for evidence accumulation in the lexical decision task. *Cogn. Psychol.* 48: 332–367.

Wixted JT and Ebbesen EB (1991) On the form of forgetting. *Psychol. Sci.* 2: 409–415.

Young JL (1971) Reinforcement-test intervals in paired-associate learning. *J. Math. Psychol.* 8: 58–81.

# 2.26 Associative Retrieval Processes in Episodic Memory

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> [Y]ou are wrong to say that we cannot move about in Time. For instance, if I am recalling an incident very vividly I go back to the instant of its occurrence: I become absent-minded, as you say. I jump back for a moment.
>
> H. G. Wells, *The Time Machine*, 1898

In the above quote from Wells' classic science-fiction novel, the protagonist compares his actual travels through time to the mental time travel one experiences through the act of reminiscence. During our childhood, many of us have fantasized about actual time travel. If we could only return to a previously experienced episode of our lives and re-experience that episode in light of our new found knowledge, perhaps that knowledge would lead us to act differently, or simply to appreciate that previous experience in new and different ways.

Although true time travel remains beyond our reach, the act of remembering is a form of time travel that we can exercise at will. Our power to remember previously experienced events can put us back in the approximate mental context of that earlier episode and allow us to interpret that episode in light of our current knowledge. In so doing, we also alter our memory of the episode in permanent ways, such that each remembering brings back not only the original encoding context, but also some elements of the context of previous rememberings.

In 1972, Endel Tulving coined the term episodic memory to refer to the form of memory that allows us to associate the many different types of information constituting an event into a spatiotemporal context and to later use the content of the event to retrieve its context. Episodic memory places us in the memory, marking the memory's position on our personal, autobiographical, timeline. Retrieval of episodic memories constitutes a form of time travel in which we recover the encoding context of the previously experienced event. Other important forms of memory, such as perceptual priming and semantic memory, do not have this feature.

Episodic memory not only supports the vivid recollection of formative life events; it also enables us to remember where we parked our car in the morning, whether we took our medicine, and whom we met at a social engagement. Dramatic failures of these everyday aspects of episodic memory can result from damage to the medial temporal lobe of the brain (Spiers et al., 2001). More subtle impairments of episodic memory accompany the normal aging process (Salthouse, 1991; Kausler, 1994).

Ever since Ebbinghaus carried out his seminal studies in 1885, most laboratory studies of human memory have focused on episodic memory. In these experiments, lists of items[1] constitute sequences of mini-experiences presented in a controlled fashion. Subjects then attempt to recall or recognize the previously studied items under a variety of conditions designed to probe and challenge their memorial abilities.

## 2.26.1 Association and Context

Association has served as the core theoretical construct throughout the history of writings on memory. An association is not observed; rather, it is inferred from the tendency of one item to evoke another. Associations that come to mind quite naturally, like the association of king and queen or of bread and butter, relate to the meaning of the constituent items. This meaning develops through extensive experience, presumably involving the temporal co-occurrence of the items in many different situations. But associations can also be formed between nominally unrelated items in a single exposure. For example, when attending closely to a pair of items presented in temporal proximity (e.g., a name–face pair) we can quickly take hold of the association, at least temporarily. Sometimes, a salient new association may be encoded well enough after a single encounter that it can be recalled, or at least recognized, after a long delay.

The classic laboratory method for studying the encoding and retrieval of episodically formed associations is the paired-associate (or cued-recall) task. In this task, subjects study a list of randomly paired words, name–face pairs, or the like. Later, subjects are presented with one member of each studied pair as a cue to recall its mate. The paired-associate task has subjects explicitly learn associations among items. In the case of words, effective learning of the paired associates depends strongly on the formation of linguistic mediators, the use of imagery, or other strategies that involve elaboration of the meaning of the constituent items (for reviews, see, Paivio, 1971; Murdock, 1974; Crowder, 1976). One may ask whether strategies are strictly necessary for the formation of associations between contiguously presented items. We will return to this question at the end of the present chapter.

The idea of interitem association only takes us so far in thinking about episodic memory. To perform any episodic task one must have some means of distinguishing the current list from the rest of one's experience. For example, if we learn the association between the words *fountain* and *piano* in one setting, and then we later learn the association between *fountain* and *slipper* in another setting, how do we flexibly retrieve either *piano* or *slipper*, and how do we recall the setting in which the word was learned?

The idea that associations are learned not only among items, but also between items and their situational or temporal context was widely recognized in the first half of the twentieth century (Hollingsworth, 1928; Carr, 1931; McGeoch, 1932; Robinson, 1932). This idea formed the basis for Underwood's classic explanation of spontaneous recovery as described in his 1945 dissertation.

Despite its recognition among early memory scholars, the idea of context available at the time was too vague to find favor among the behavioristically oriented learning scholars who dominated in the post-war period (McGeoch and Irion, 1952). Whereas associations could be viewed as an experimentally determined increase in the probability of a stimulus evoking a response, context is not easily tied to experimental manipulations. To scholars of a strictly empirical orientation, the difficulty of controlling and manipulating context, especially internally generated context, greatly limited its utility as an explanatory construct. These scholars feared the admission of an ever-increasing array of hypothesized and unmeasurable mental constructs into the scientific vocabulary (e.g., Slamecka, 1987).

The notion of temporal context regained respectability in the memory literature after the appearance of Gordon Bower's temporal context model in 1972 (Bower, 1972; see also, Bower, 1967). The related notion of temporal coding processes was also emphasized by Tulving and Madigan (1970) in their influential review of the state of the field. According to Bower's model, contextual representations are composed of many features which fluctuate from moment

[1] Although Ebbinghaus used consonant-vowel-consonant (CVC) syllables as stimuli, most modern studies use words due to their relatively consistent interpretation and coding across participants.

to moment, slowly drifting through a multidimensional feature space. Whereas previous investigators had noted the importance of temporal coding (e.g., Yntema and Trask, 1963), Bower's model, which drew heavily on the classic stimulus-sampling theory developed by William K. Estes (1955), placed the ideas of temporal coding and internally generated context on a sound theoretical footing. The Bower–Estes model provided the basis for more recent computational models of temporal context and its central role in episodic memory (Mensink and Raaijmakers, 1988; Howard and Kahana, 2002).

## 2.26.2 Associative Processes in Free Recall

The cognitive revolution of the 1960s brought a shift away from the paired-associate and serial learning tasks which had served as the major experimental approach to the study of human verbal memory until that time. The more cognitively oriented researchers were especially drawn to free recall. In the free recall task, subjects study a sequence of individually presented items. At test, they are simply asked to recall all of the items they can remember in any order they wish.[2] There is no experimenter-imposed structure on the nature of the recall process. By analyzing the order in which subjects recall list items, one can gain considerable insights into the memory processes operating under these relatively unconstrained conditions. In contrast, the paired-associate task imposes a strong, experimenter-defined, organization on the to-be-learned materials: subjects are aware that they must link the paired items at study and that they will later be asked to recall a specific target item in response to a given cue.

The scientific literature on free recall has followed two distinct strands. One strand of research focused on how subjects learn a list over the course of successive study-test trials. In a classic study, Tulving (1962) demonstrated that over repeated trials in which the input sequence is randomized, the sequences of recalled items becomes increasingly consistent from trial to trial. In learning lists of random words, subjects appeared to create a kind of organization of the materials, with the level of recall tracking the degree of organization (see Sternberg and Tulving, 1977, for a review of measures of subjective organization). Earlier work by Bousfield and colleagues (Bousfield, 1953; Bousfield et al., 1954) had shown that when subjects studied lists that included strong semantic associates, their sequence of recalls was organized semantically, a phenomenon termed category clustering. Tulving's work showed that organization was a far more general phenomenon, seen even in lists whose items lacked any obvious categorical or semantic organization. Tulving's work on organization and memory spawned several decades of work aimed at understanding the role of organization in the learning process (see Tulving, 1983, for a review).

The second strand of research on free recall focused on how subjects recalled a list after a single study trial. In his classic analysis of the serial position curve in free recall, Murdock (1962) reported the relation between list position and recall probability. On an immediate recall test, subjects exhibited a striking recency effect, recalling the last few items more frequently than items from earlier list positions. These recency items were typically the first items recalled in the sequence of responses (Deese and Kaufman, 1957; Nilsson et al., 1975). Among the earlier (prerecency) items, subjects exhibited superior recall for the first three or four list items than for items from the middle of the list (the primacy effect).

Murdock varied both list length and presentation rate, and found that both manipulations produced a dissociation between the level of recall of recency and prerecency items. Specifically, he found that increasing list length or speeding the presentation rate resulted in lower recall of early and middle items, but did not affect recall of the more recent items. In addition to list length and study time (presentation rate), other variables that boost recall of prerecency items have little or no effect on recency items. For example, lists of similar words are better recalled than unrelated words (Craik and Levy, 1970), and lists of common words are better recalled than lists of rare words (Sumby, 1963; Raymond, 1969; Ward et al., 2003).[3] In both of these cases, however, the enhanced recall is not seen for the recency items. In contrast, the recency effect is significantly greater for auditorally than for visually presented lists, while modality of presentation has no effect on prerecency items (Murdock and

[2] In 1894, E. A. Kirkpatrick published the first study using the free-recall method. This was the same year that Mary Calkins introduced the paired-associate technique. Because of the unconstrained nature of the free-recall technique, Ebbinghaus (1911) found it to be crude and superficial. However, interest in free recall surged following a series of influential studies published between 1953 and 1962 by Weston Bousfield, James Deese, Ben Murdock, Leo Postman, and Endel Tulving.

[3] In item recognition, normative word frequency has the opposite effect, with rare words being better recognized than common words (MacLeod and Kampe, 1996).

Walker, 1969). Moreover, asking subjects to perform a brief unrelated distractor task at the end of the list (e.g., solving arithmetic problems for 15 s) greatly reduces the recency effect while having no adverse consequences on recall of prerecency items (Postman and Phillips, 1965; Glanzer and Cunitz, 1966). **Figure 1(a)** shows the effect of a brief distractor task on the serial position curve in free recall. These and other dissociations between recency and prerecency led many investigators to embrace the notion of distinct memory systems: a short-term store (STS) responsible for the recency effect, and a long-term store (LTS) responsible for the primacy effect and for the level of recall for prerecency items (Waugh and Norman, 1965; Atkinson and Shiffrin, 1968; Glanzer and Cunitz, 1966).

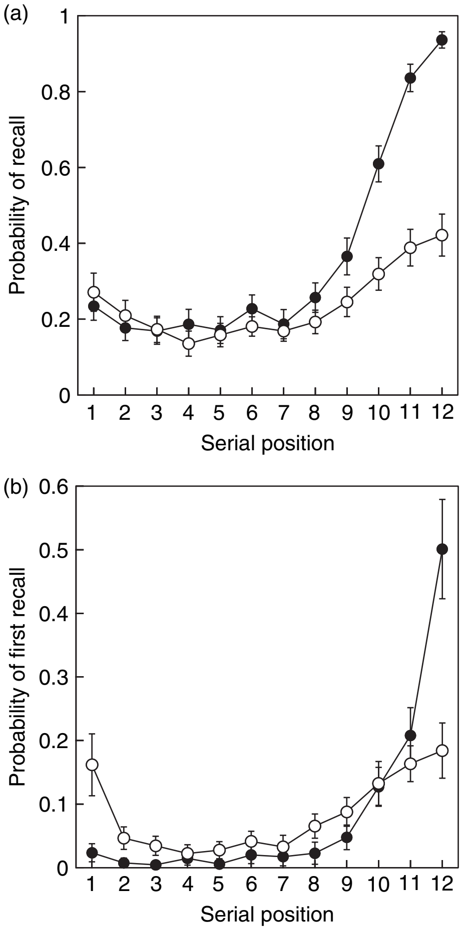


**Figure 1** The recency effect in immediate and delayed free recall. After studying a list of 12 common words, subjects were either asked to recall items immediately (filled circles) or following a 15-s arithmetic distractor task (open circles). (a) Serial position curves. (b) Probability of first recall functions show the probability that the first recalled item was presented in a given serial position. These functions thus illustrate the relative tendency to begin recall with primacy or recency items. Data are from Howard MW and Kahana MJ (1999) Contextual variability and serial position effects in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 923–941 (Experiment 1). Error bars denote 95% confidence intervals.

### 2.26.2.1 Retrieval Dynamics in Free Recall

Although traditional serial position-based analyses fueled much of the theoretical debate concerning the memory processing underlying free recall (and for that matter serial recall), such analyses discard information about sequential dependencies in retrieval, information which is crucial for understanding the structure of episodic memory storage, and the process of episodic memory retrieval. By measuring the order in which list items are recalled, we can decompose the retrieval process into a measure of how subjects initiate recall and a measure of how they make transitions among successively recalled items.

As mentioned above, subjects typically initiate recall with one of the final list items. This tendency can be quantified by measuring the probability with which subjects initiate recall at each serial position. **Figure 1(b)**, which shows the probability of first recall as a function of serial position, reveals a strong tendency for subjects to initiate recall with one of the final list items (Hogan, 1975; Laming, 1999). In delayed free recall, this tendency is markedly diminished (Howard and Kahana, 1999). By studying subjects' subsequent recall transitions, one can see that temporally defined, interitem associations exert a strong influence on output order and inter-response times in free recall. These associations are inferred from participants' tendency to successively recall items from nearby list positions. As shown in **Figure 2(a)**, the probability of recalling a word from serial position $i +$ lag immediately following a word from serial position $i$ is a sharply decreasing function of $|\text{lag}|$. Positive values of lag correspond to forward recall transitions; negative values of lag correspond to backward recall transitions.[4] In calculating the conditional response probability as a

[4] For example, if the list had contained the subsequence '*absence hollow pupil*' and a participant recalled *hollow* then *pupil*, the recall of *pupil* would have a lag of +1. If, instead, the participant recalled *hollow* then *absence*, the recall of *absence* would have a lag of −1. In this case, the participant is moving backward in the list. *Absence* followed by *pupil* would yield a lag of +2.

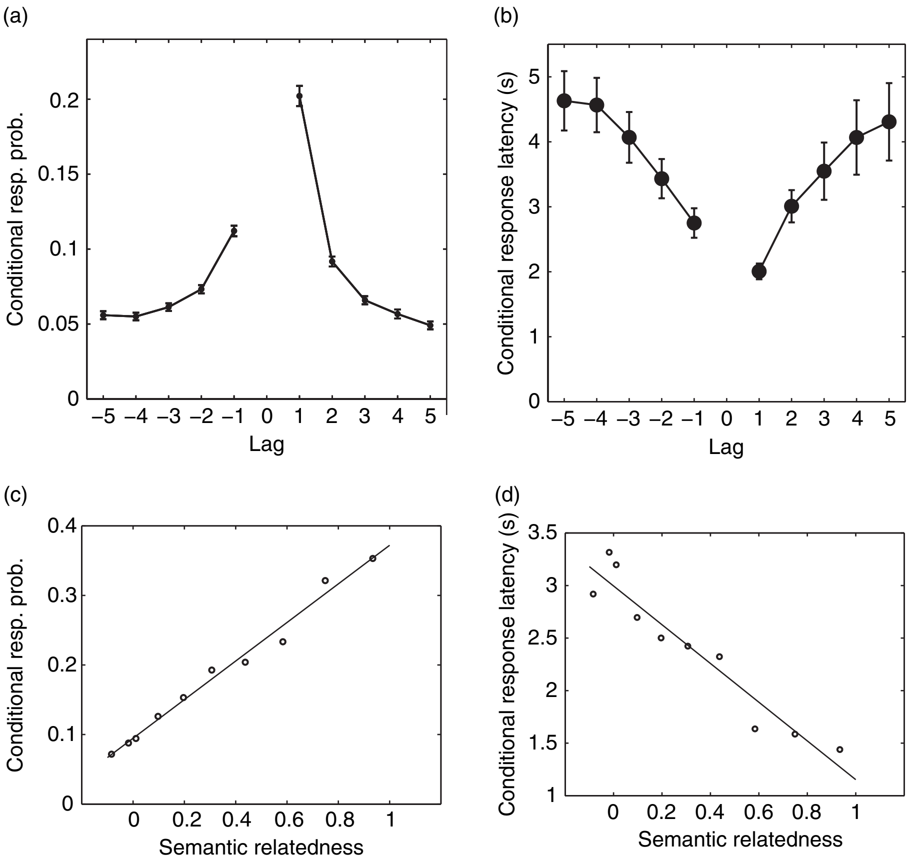


**Figure 2** Associative processes in free recall: effects of temporal contiguity and semantic relatedness. (a) The conditional–response probability as a function of lag (or lag-CRP) shows the probability of recalling an item from serial position $i+\text{lag}$ immediately following an item from serial position $i$. This curve is based on data from 20 experimental conditions (Murdock BB (1962) The serial position effect of free recall. *J. Exp. Psychol.* 64: 482–488; Murdock BB and Okada R (1970) Interresponse times in single-trial free recall. *J. Verb. Learn. Verb. Behav.* 86: 263–267; Murdock BB and Metcalfe J (1978) Controlled rehearsal in single-trial free recall. *J. Verb. Learn. and Verb. Behav.* 17: 309–324; Roberts WA (1972) Free recall of word lists varying in length and rate of presentation: A test of total-time hypotheses. *J. Exp. Psychol.* 92: 365–372; Kahana MJ, Howard MW, Zaromb F, and Wingfield A (2002) Age dissociates recency and lag recency effects in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 28: 530–540; Howard MW and Kahana MJ (1999) Contextual variability and serial position effects in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 923–941; Zaromb FM, Howard MW, Dolan ED, Sirotin YB, Tully M, Wingfield A, et al. (2006) Temporal associations and print-list intrutions in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 32(4), 792–804; Kimball DR and Bjork RA (2002) Influences of intentional and unintentional forgetting on false memories. *J. Exp. Psychol. Gen.* 131: 116–130; Kahana MJ and Howard MW (2005) Spacing and lag effects in free recall of pure lists. *Psychon. Bull. Rev.* 12: 159–164; Kahana MJ, Dolan ED, Sauder CL, and Wingfield A (2005a) Intrusions in episodic recall: Age differences in editing of overt responses. *J. Gerontol. Psychol. Sci.* 60: 92–97). (b) The conditional-response latency as a function of lag (or lag-CRL) shows the mean inter-response time between successive recalls of items from serial positions $i$ and $i+\text{lag}$ (Howard MW and Kahana MJ (1999) Contextual variability and serial position effects in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 923–941; Murdock BB and Okada R (1970) Interresponse times in single- trial free recall. *J. Verb. Learn. Verb. Behav.* 86: 263–267; Zaromb FM, Howard MW, Dolan ED, Sirotin YB, Tully M, Wingfield A, et al. (2006) Temporal associations and prior-list intrutions in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 32(4): 792–804; Kahana MJ, and Howard MW (2005) Spacing and lag effects in free recall of pure lists. *Psychon. Bull. Rev.* 12: 159–164). Error bars represent 95% confidence intervals across experiments. (c) The conditional-response probability as a function of semantic relatedness (semantic-CRP) reveals that subjects are more likely to recall items that are semantically related to the just-recalled item. Semantic-relatedness was measured using the word-association space technique (Steyvers M, Shiffrin RM, and Nelson DL (2004) Word association spaces for predicting semantic similarity effects in episodic memory. In: Healy AF (ed.) *Cognitive Psychology and its Applications: Festschrift in Honor of Lyle Bourne, Walter Kintsch, and Thomas Landauer*. Washington, DC: American Psychological Association). (d) The conditional-response latency as a function of semantic relatedness (semantic-CRL) shows that subject transitions are made more quickly when they are to related items.

function of lag, or lag-CRP, we estimate the probability of a transition to a given lag by dividing the number of transitions to that lag by the number of opportunities to make a transition to that lag.

### 2.26.2.2 The Contiguity Effect

The analysis of retrieval transitions in free recall reveals a strong tendency for neighboring items to be recalled successively. We refer to this phenomenon, illustrating participants' reliance on temporal associations to guide recall, as the contiguity effect. As shown in **Figure 2(a)**, the contiguity effect exhibits a marked forward bias, with associations being stronger in the forward than in the backward direction. The basic form of the contiguity effect does not appear to depend on experimental manipulations. The lag-CRP functions are virtually identical across manipulations of presentation modality (visual vs. auditory), list length, and presentation rate (Kahana, 1996).

The contiguity effect also appears in the form of shorter inter-response times between recall of items from neighboring list positions. This can be seen in the conditional response latency (lag-CRL) function shown in **Figure 2(b)** (see Kahana and Loftus, 1999, for a further discussion of the accuracy–latency relation). The contiguity effect, as seen in both accuracy and latency data, may reflect a kind of mental time travel undertaken during memory search and retrieval. In recalling an item, the subject may 'travel back' to the time of its presentation, making it more likely that subsequent recalls will come from nearby serial positions.

### 2.26.2.3 The Semantic Proximity Effect

In free recall, participants do not rely solely on newly formed episodic associations; they also make use of their pre-existing semantic associations among list items. We can quantify subjects' use of semantic associations in free recall by computing the conditional probability of a recall transition as a function of an item's semantic relatedness to the just-recalled item (we term this function the semantic-CRP). This approach requires a measure of the semantic relatedness of arbitrary word pairs. To obtain such measures, we turn to computational models of semantic spaces. Landauer and Dumais (1997) developed latent semantic analysis (or LSA); this project involved the statistical analysis of a large text corpus, allowing them to derive a measure of word-relatedness from the tendency for words that share meaning to co-occur in paragraphs. Steyvers et al. (2004) developed a word association space (or WAS) based on the large University of South Florida word association database (Nelson et al., 2004). Both LSA and WAS provide measures of the semantic relatedness for a great many pairs of words in the English language. The measure is quantified as the cosine of the angle between the vectors representing the two words in a high-dimensional space. Completely unrelated words would have $\cos\theta \approx 0$, and strong associates would have $\cos\theta$ values between 0.4 and 1.0. For a more thorough treatment and discussion, see Howard et al. (2007).

The semantic-CRP shows that the stronger the semantic relation between two list words, the more likely it is that they would be successively recalled (**Figure 2(c)**). In addition, the stronger the semantic association between two successively recalled words, the shorter the inter-response time would be between the two words (**Figure 2(d)**). This analysis illustrates the powerful influence of semantic relatedness on recall of randomly chosen word lists. Even when lists lack any strong associates or any obvious categorical organization, recall transitions are driven by the relative semantic strengths among the stored items. Consistent with the findings of category clustering and subjective organization described above, the contiguity effect decreases, and the semantic-proximity effect increases, across learning trials in which the order of word presentation at study is randomized on each trial (Klein et al., 2005; Howard et al., 2007).

### 2.26.2.4 Normal Aging Affects Contiguity but Not Recency

It is well known that older adults perform more poorly on episodic memory tasks than their younger counterparts (Verhaeghen and Marcoen, 1993; Kausler, 1994). The age-related memory impairment is particularly marked in recall tasks that require subjects to use temporally defined associations, such as cued recall and free recall (Naveh-Benjamin, 2000; Wingfield and Kahana, 2002; Hoyer and Verhaeghen, 2006).

The analysis of retrieval transitions, as described above, can be used to directly assess subjects' reliance on temporal associations in free recall. Kahana et al. (2002) examined the difference between recency and contiguity effects in younger and older adults. Half of the subjects in each age group were given an immediate free recall test; the other half were given a delayed free recall test. As expected, younger adults recalled more words on both immediate and delayed tests, and the distractor task attenuated the recency effect for subjects in both age groups. The critical finding was that older adults exhibited a significantly diminished contiguity effect, as seen in their lag-CRP functions (**Figure 3(b)**). In contrast, younger and older adults initiated recall in the same manner; their probability of first recall functions were virtually identical both in the immediate and in the delayed free-recall conditions (**Figure 3(a)**). Although older adults exhibited a markedly reduced contiguity effect, their semantic-proximity effect was unimpaired (unpublished observation). These findings suggest that the mnemonic deficit observed for older adults is largely restricted to the ability to form and/or utilize temporally defined associations. This is consistent with previous reports of age-related deficits in the formation and retrieval of episodic associations (e.g., Naveh-Benjamin, 2000).

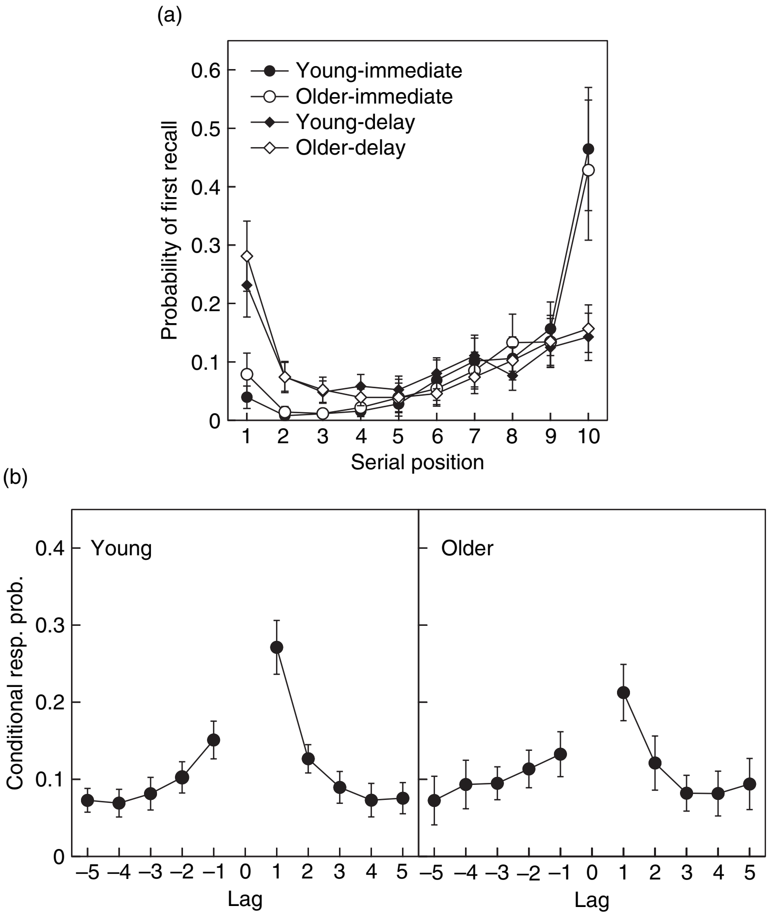


**Figure 3** Selective effect of aging on associative processes in free recall. (a) Probability of first recall from immediate and delayed free recall for younger and older adults. Data taken from Kahana MJ, Howard MW, Zaromb F, and Wingfield A (2002) Age dissociates recency and lag recency effects in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.,* 28: 530–540. Figure reprinted with permission from Howard MW, Addis KA, Jing B, and Kahana MJ (2007) Semantic structure and episodic memory. In: McNamara D and Dennis S (eds.), *LSA: A Road Towards Meaning.* Hillsdale, NJ: Laurence Erlbaum and Associates. (b) Conditional response probability (CRP) for younger and older adults from the delayed condition of Kahana MJ, Howard MW, Zaromb F, and Wingfield A (2002) Age dissociates recency and lag recency effects in free recall. *J. Exp. Psychol. Learn. Mem. Cogn., 28*, 530–540.

### 2.26.2.5 Long-Range Interitem Associations

Bjork and Whitten (1974) conducted an experiment which challenged the traditional STS-based account of recency effects in free recall. They were interested in seeing how well subjects could recall a list of word pairs under conditions designed to eliminate between-pair rehearsal. To eliminate between-pair rehearsal, they had subjects perform a difficult distractor task following the appearance of each pair, including the last one. Because the distractor was expected to displace any items in STS, Bjork and Whitten did not expect to find a recency effect. To their surprise, they found a strong recency effect, with the final few pairs being recalled better than pairs from the middle of the list. They called this the long-term recency effect. Their procedure, in which a distractor task is given following every item, including the last, is called continuous-distractor free recall. **Figure 4** illustrates the continuous-distractor free recall procedure alongside the more traditional immediate and delayed free recall procedures.

| Condition | Recency |
|---|---|
| Immediate<br>PEN CAR ROSE ··· BIRD *** | Yes |
| Delayed<br>PEN CAR ROSE ··· BIRD [1+2=] *** | No |
| Continuous distractor<br>PEN [6+2=] CAR [3+7=] ROSE [1+1=] ··· BIRD [2+5=] *** | Yes |

**Figure 4** Illustration of immediate, delayed, and continuous-distractor paradigms. The row of asterisks indicates the start of the recall period.

The long-term recency effect has now been replicated many times using both single words and word pairs, and across delays ranging from tenths of seconds (Neath, 1993) to days (Glenberg et al., 1983). The magnitude of the long-term recency effect depends critically on both the duration of the distractor given after the last word (the retention interval) and on the duration of the distractor intervening between list words (the interpresentation interval). For a given retention interval, increasing the interpresentation interval results in more recency and better recall of the final item.

Kahana (1996) interpreted the contiguity effect as evidence for associations formed in STS. If associations are formed between items that are active together in STS (as postulated by Glanzer, 1972; Raaijmakers and Shiffrin, 1980), then this would predict the contiguity effect because nearby items spend more time together in STS than remote items. However, because a long interitem distractor should displace items in STS, the contiguity effect should be significantly attenuated in continuous-distractor free recall.

Howard and Kahana (1999) tested this hypothesis by measuring the contiguity effect in continuous-distractor free recall. **Figure 5(a)** illustrates the contiguity effect for interpresentation intervals ranging from 0 s (standard delayed free recall) to 16 s. As can be seen, the contiguity effect was relatively constant across this range of interpresentation intervals. This result is quantified in **Figure 5(b)** by fitting a power function ($P = a|\text{lag}|^{-b}$) to each participant's lag-CRP curve and using the $b$ parameter as an estimate of the contiguity effect (the $a$ parameter determines the overall scale of

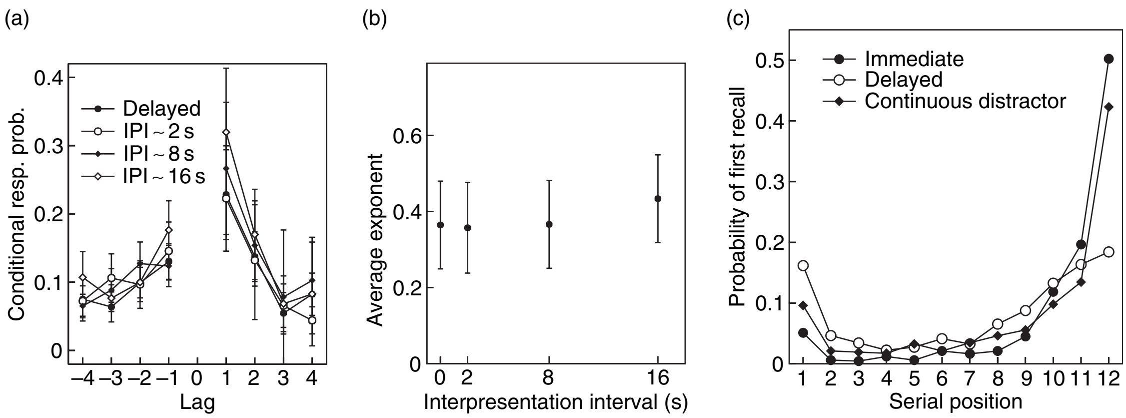


**Figure 5** Long-range contiguity and recency effects. (a) Lag-CRP as a function of the length of the distractor task in continuous-distractor free recall. (b) To quantify the contiguity effect, power functions were fit to the lag-CRP curves for each participant in each condition. Error bars represent 95% confidence intervals. (c) The probability of first recall functions for immediate, delayed, and continuous-distractor free recall (Howard and Kahana, 1999).

the function). Insofar as the contiguity effect is insensitive to the absolute delay between list items, it exhibits an approximate time-scale invariance. Although 16 s of a distractor had virtually no impact on the contiguity effect, the same amount of distractor activity presented at the end of the list was sufficient to eliminate the end-of-list recency effect (**Figure 5(c)**).

As shown in **Figure 5**, the contiguity effect persists even when the study items are separated by 16 s of a demanding distractor task. However, recent work shows that the contiguity effect is evident on even longer time scales. Howard et al. (2008) presented subjects with a series of lists for free recall. At the conclusion of the session, subjects were given a surprise final free recall test in which they were instructed to remember as many words as possible from the 48 study lists in any order. Howard et al. (2008) measured the contiguity effect in this final free recall period both for transitions within a list as well as between lists. They found that transitions between nearby lists were more frequent than transitions between lists that were farther apart in the experiment. This contiguity effect extended about ten lists, or several hundred seconds, extending the range over which contiguity effects are observed in free recall by a factor of ten. Moreover, this paradigm offers several potential advantages over continuous-distractor free recall. In continuous distractor free-recall, subjects have an incentive to try and rehearse items across the distractor intervals. Because the subject is only asked to recall the most recent list in the Howard et al. (2008) study, and intrusions from prior lists are scored as errors, there is no strategic reason for subjects to rehearse across lists in anticipation of the surprise final free recall test. In continuous-distractor free recall, the consistency of associations across delay intervals was inferred from observing lag-CRP curves across conditions that differed in their IPI. It is conceivable that this was due in part to different strategies across experimental conditions. In contrast, in the Howard et al. (2008) study, both within-and across-list associations were observed simultaneously during the final free recall period.

#### 2.26.2.6 Interim Summary

We have shown how both temporal contiguity and semantic relatedness strongly predict the order and timing of subjects' responses in the free-recall task. The contiguity effect (**Figure 2(a, b)**) illustrates how episodic associations are graded, exhibiting power-function decay with increasing lag. Recall of an item has a tendency to evoke not only adjacent list items, but other nearby items as well. In addition, episodic associations appear to be asymmetrical, favoring retrieval of items in the forward order.

Whereas the previous two characteristics of episodic association can be accommodated within the view that neighboring items become associated when they cooccupy a short-term buffer (or working memory system), analyses of episodic association in continuous-distractor free recall show that the contiguity effect persists across time scales. That is, using a distractor task to temporally segregate list items does not disrupt the associative mechanism. Moreover, contiguity can even be observed in recall transitions among items studied as part of different lists, separated by several minutes. The tendency for an item to evoke a nearby item thus depends on the relative spacing, not the absolute spacing, of the list items.

A critical question for memory theory is whether the contiguity effect is specific to free recall, or whether similar associative processes operate in other memory tasks. It is possible that some of the phenomena described in the preceding section are a consequence of specific strategies that subjects use in the free-recall paradigm. In particular, by allowing participants to recall items in any order, we may be observing participants' biases in favoring particular kinds of transitions (e.g., forward over backward, adjacent over remote) rather than revealing the underlying associative structure. This criticism is blunted by our finding that the lag-CRP and lag-CRL functions vary little across experiments that differ significantly in their methodologies, even including the introduction of a long interitem distractor (see **Figure 5**). Nonetheless, it is important to take a broader look at the question of associative processes in episodic memory. In the next section, we show how associative processes can be seen in the pattern of subjects' errors in free recall, serial recall, and cued recall. We then examine the question of associative processes in item recognition. The final section of this chapter discusses these empirical data in terms of the major theories of associative processes in episodic memory.

### 2.26.3 Memory Errors Reveal Associative Processes

The study of the errors made in a variety of memory tasks shows that even when the memory system goes awry and produces a response that is incorrect in the context of a given experiment, the processes generating this error appear to be influenced by the same factors that guide correct responses. In this section, we consider how subjects' recall errors reveal characteristics of the associative processes operating in free recall, serial recall, probed recall, and cued recall tasks.

### 2.26.3.1 Prior-List Intrusions in Free Recall

It is well known that incorrect recalls (intrusions) often arise due to the semantic relations between studied and nonstudied items. For example, after studying a list of items that include the semantic associates of a critical word, participants often incorrectly recall that critical word even though it was not presented on the list (Deese, 1959; Roediger and McDermott, 1995; Roediger et al., 1998; Gallo and Roediger, 2002). Although semantic association is a major determinant of false recall, episodic memory processes also appear to play an important role. For example, in free recall of randomly arranged word lists, prior-list intrusions – incorrect recalls of words that were presented on an earlier list – are often more frequent than extralist intrusions – incorrect recalls of words that were not presented during the course of the experiment. This suggests that the recent study of an item increases the probability that it will be (incorrectly) recalled. Moreover, prior-list intrusions exhibit a strong recency effect, being most likely to come from the list immediately preceding the target list (Murdock, 1974; Zaromb et al., 2006); the number of prior-list intrusions coming from earlier lists decreases sharply (see **Figure 6(a)**).

In a recent study, Zaromb et al. (2006) asked whether contiguity-based associations would also tend to induce false recall. They conducted several free-recall experiments in which some items in a given list had also appeared on earlier lists. In all cases, participants were instructed to recall only the items from the most recently presented list. By creating lists that contained mixtures of novel items and items repeated from earlier lists, Zaromb et al. found that recalls of repeated items were more likely to be followed by prior-list intrusions than were recalls of novel items. This finding would emerge if temporal associations forged on prior lists compete with the associations formed in the current list, and if these older associations occasionally win in the competition. As further support for the role of contiguity-based associations, Zaromb et al. found that repetition-evoked prior-list intrusions came from the same prior lists as the repetitions themselves, and from positions near the repetitions in those lists. When subjects committed two same-list prior-list intrusions in succession, those intrusions tended to come from neighboring positions in their original list, exhibiting a temporal contiguity effect similar to that seen for correct recalls (see **Figure 6(b)**).

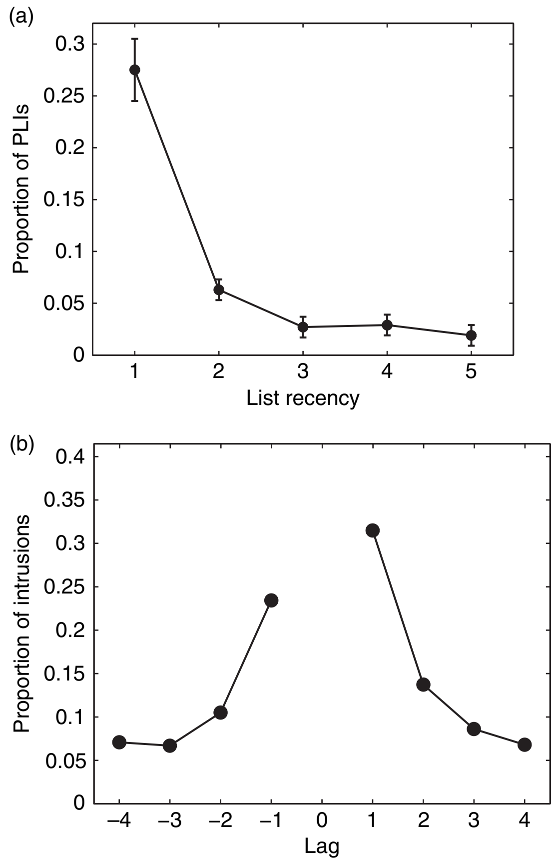


**Figure 6** Effects of recency and contiguity on intrusions in free recall. (a) Prior-list intrusion (PLI) recency effect. Proportion of intrusions coming from one to five lists back. In calculating these PLI-recency functions for items originally presented one to five lists back, we excluded the first five trials from the analysis. That is because PLIs from five lists back could only occur on trials 6 and later. (b) Successive PLIs that came from the same original list tend also to come from neighboring positions in their original list. Thus, temporally defined associations influence PLIs in free recall (Zaromb et al., 2006).

### 2.26.3.2 Intrusions in Serial and Probed Recall

We next consider the effect of contiguity on retrieval in serial-order memory. In a serial-recall task, participants are instructed to recall the list items in order of presentation, rather than in any order as in free recall. In requiring ordered recall, the serial-recall task demands that subjects store information not only about which items were on the list, but also about their order. Thus, the serial-recall task exerts greater control over the manner of encoding and retrieval than does free recall.

Although subjects can only make one correct response in a given output position, they can commit many different types of errors. The orderly pattern of subjects' errors in serial recall can teach us a great deal about the underlying processes. For example, it is well known that when recalling an item in the wrong position this item tends to be misplaced near the correct (target) position (e.g., Lee and Estes, 1977). This finding has also been documented extensively in reordering tasks, where subjects are given all of the target items and asked to place them in their correct studied order (e.g., Nairne, 1990a, 1990b).

The traditional method for measuring error gradients is to plot the probability of an item studied in serial position $i$ being recalled in position $i+$ lag. This approach works especially well in reordering tasks where all the items are placed in some position. With longer lists, where only some of the items are recalled, it is especially important to correct for the availability of different lags, as we have done in our lag-CRP analysis of free recall. For these lag-CRP analyses, we compute the probability of recalling an item from position $i$ in position $i+$ lag conditional on the possibility that an item could be placed in position $i+$ lag (for example, we make sure that the item from that position has not already been recalled). **Figure 7(a)** shows an analog of the lag-CRP derived from errors observed during serial recall (Kahana and Caplan, 2002). In addition to revealing the tendency for errors to come from nearby list positions, this curve shows a clear asymmetry effect, with errors in the forward direction being significantly more likely than errors in the backward direction.[5] Thus, the temporal gradient of errors in serial recall is strikingly similar to the temporal gradient of correct responses observed in free recall (see Klein et al., 2005, for a direct comparison of free recall and serial recall).

The analysis of errors in serial recall is complicated by the fact that each response depends on the sequence of prior responses (Giurintano, 1973). An alternative approach to measuring serial-order memory is to present subjects with a single item from a previously studied list and ask them to recall the item that preceded or followed the probe item (Murdock, 1968; Woodward and Murdock, 1968). Analysis of error gradients obtained in forward and backward probed recall provide an even cleaner test of the asymmetry effect observed in both free and serial recall. **Figure 7(b)** shows error gradients in a probed recall study reported by Kahana and Caplan (2002). The top panel shows that when subjects were given item $i$ and asked to recall item $i+1$, responses tended to come from nearby positions, with a forward bias ($i+2$ is more likely than $i-1$). The bottom panel of **Figure 7(b)** shows that when subjects were probed in the backward direction (i.e., given item $i$ and asked to recall item $i-1$), the same forward asymmetry was obtained (see also Raskin and Cook, 1937).

### 2.26.3.3 Intrusions in Paired-Associate Recall

The preceding section documented two characteristics of errors in serial recall and in probed recall of serial lists: (1) subjects' intrusions tend to be items studied near the position of the target item and (2) subjects' error gradients exhibit a forward asymmetry, with errors being more likely to be items following than items preceding the target item. The temporal gradient of retrieval transitions in free recall as seen in the lag-CRP, and the gradient of subjects' intralist intrusion errors in both serial and probed recall could reflect a common methodological aspect of these tasks. In both free and serial recall tasks, the to-be-learned items constitute an unbroken series such that storing and retrieving associations among neighboring items is useful for performing the task. An important exception to this is continuous-distractor free recall, in which list items are separated by a demanding distractor task. Nonetheless, even in continuous-distractor free recall, subjects may be motivated to make associations between neighboring items.

Paired associate memory provides an interesting contrast to both free and serial recall. In the standard paired-associate procedure, subjects are asked to learn a list of nonoverlapping pairs of words. Following this study phase, subjects are cued for recall of specific pairs (either in the forward or the backward order). Unlike free and serial recall, in which subjects must learn an entire list, subjects in the paired-associate task have no reason to learn associations other than those binding the items within

[5] As with the lag-CRP analysis of free recall, this analysis corrects for the number of available to-be-recalled items.

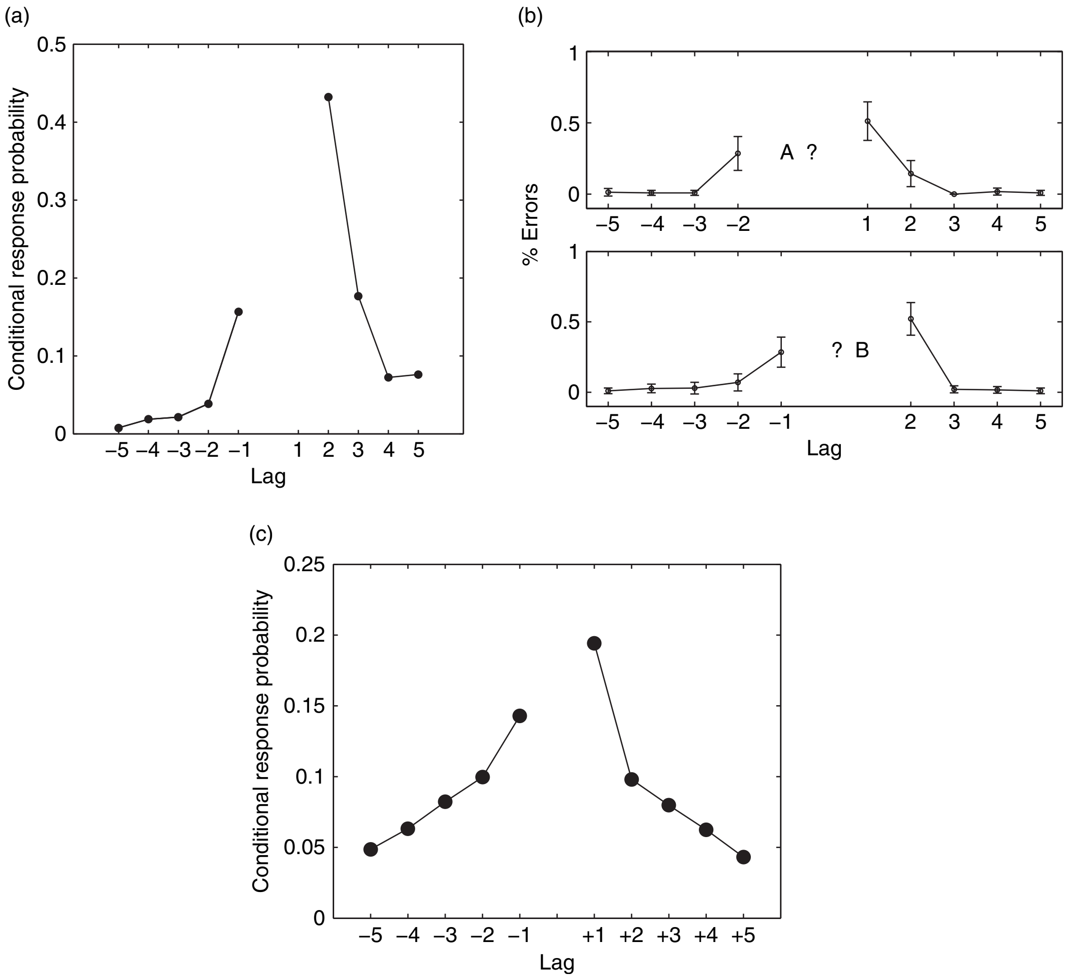


**Figure 7** Intrusions reveal associative tendencies in serial-recall, probed-recall, and cued-recall tasks. (a) Lag-CRP analysis of errors in immediate serial recall. Correct responses (lag of +1) were excluded from this analysis. (b) Conditional error gradients in forward (top) and backward (bottom) probed recall; subjects are given item $i$ as a cue for item $i+1$ (upper panel), or $i-1$ (lower panel), and they recall some other item $i+$ lag. Data are from Trial 1 of Kahana and Caplan's second experiment (Kahana MJ and Caplan JB (2002) Associative asymmetry in probed recall of serial lists. *Mem. Cognit.* 30: 841–849). (c) Following study of 12 randomly chosen noun-noun pairs, subjects were given a standard cued recall test. The probability of incorrectly recalling a word from pair-$j$ in response to a cue word from pair-$i$ decreased with increasing lag, measured in pairs. (Davis OC, Geller AS, Rizzuto DS, and Kahana MJ (2008) Temporal associative processes revealed by intrusions in paired-associate recall. *Psychon. Bull. Rev.* 15(1): 64–69).

each studied pair. Recall is strictly cued by the experimenter so there is no benefit to recalling any item other than the one being probed. Whereas associations in both free and serial recall have a strong forward bias, associations in paired-associate tasks are generally symmetric, with nearly identical recall rates for forward and backward probes (for reviews see Ekstrand, 1966; Kahana, 2002). This surprising result led Gestalt psychologists to propose an *associative symmetry hypothesis* (Köhler, 1947; Asch and Ebenholtz, 1962). According to this hypothesis, associations are learned by incorporating the representations of the constituent items into a new holistic representation. Formalized in computational models, this hypothesis implies that the strengths of forward and backward associations are approximately equal and highly correlated (Rizzuto and Kahana, 2001; Kahana, 2002; Caplan et al., 2006; Sommer et al., 2007).

In light of the distinct features of the paired-associate task, one may wonder whether subjects form temporal associations beyond those required to learn the pairings set forth in the experiment. Davis et al. (2008) addressed this question by examining subjects' pattern of intralist intrusions in paired associate recall. In a cued recall task, there are a number of types of errors a subject could make. Intralist intrusions are incorrect responses where the subject recalls an item from a different pair than the cue came from. Davis et al. (unpublished data) hypothesized that if a common associative process underlies all recall tasks, intralist intrusions would be more likely to come from neighboring list pairs. Consistent with CRP analyses from other paradigms, Davis et al. conditionalized the probability of committing an intrusion from a given lag on the availability of the pair at that lag. Although intralist intrusions constituted only 5% of subjects' responses, these intrusions exhibited a strong tendency to come from neighboring pairs. This can be seen in **Figure 7(c)**, which shows that the conditional probability of an intralist intrusion decreased monotonically with the number of pairs (lag) separating the intrusion from the probed item. This effect was not limited to an increased tendency to commit intrusions from adjacent pairs; even when adjacent pairs were excluded, a regression analysis demonstrated that the across-pair contiguity effect was highly reliable.

Because the order of test was randomized with respect to the order of study, there was no reason for subjects to adopt a strategy of learning interpair associations. Indeed, such a strategy would have been counterproductive insofar as it would induce high levels of associative interference between pairs (Primoff, 1938). As such, these findings of associative tendencies in subjects' intralist intrusions suggest that these temporally defined associations arise from a basic and most likely obligatory memory process that causes items studied in nearby list positions to become associatively connected.

This spectrum of findings reveals that free recall is not alone in providing evidence for the centrality of contiguity effects in human memory. All of the major recall paradigms – free recall, serial recall, and paired-associates learning – show graded effects of temporal contiguity; in many cases these effects are revealed in the patterns of errors made by subjects. Taken together, these findings allow us to glimpse the workings of a general-purpose 'engine of association' that is tapped by all of these varied tasks. Furthermore, the observation of long-range contiguity, both in free recall and in subjects' intrusions in paired-associate recall, challenges the view that intentional encoding is necessary for the formation of contiguity-based associations.

## 2.26.4 Associative Processes in Item Recognition

Theories of item recognition and cued recall typically assume that these two tasks are based on distinct and possibly independent sources of information (Murdock, 1982; Gillund and Shiffrin, 1984; Kahana et al., 2005b) According to these theories, item recognition relies on item-specific information, whereas recall tasks rely on associative (or relational) information (Humphreys, 1978; Hunt and McDaniel, 1993). This view is supported by experimental dissociations between item recognition and free recall (e.g., the word frequency effect; Kinsbourne and George, 1974) and by the finding that words that are recallable often cannot be recognized, and vice versa (e.g., Tulving and Thompson, 1973; Tulving and Wiseman, 1975).

Despite these differences between recall and recognition, both tasks assess memory for an event encoded within a temporal context. Given the ubiquitous character of the contiguity effect across all of the major recall paradigms, it is natural to ask whether contiguity exerts some influence on retrieval in item recognition, at least under conditions where subjects' recognition judgments are accompanied by a feeling of recollection. More specifically, one might hypothesize that recognizing an item as having been previously studied would partially reinstate the item's encoding context, which in turn might facilitate subsequent recognition of neighboring items.

To test this hypothesis, Schwartz et al. (2005) manipulated the serial lag between successive memory probes in an item recognition study that used landscape photos as stimuli. The recognition test was a sequence of test probes that included the old items from the list intermingled with an equal number of new items that served as lures. Subjects pressed one of six keys in response to each probe, rating their confidence that it was seen before from 1 (sure new) to 6 (sure old). A recognition test might include the subsequence of test probes ($\ldots O_{23}$, $N$, $O_{12}$, $O_7$, $N$, $N$, $O_{39}, \ldots$), where $N$ denotes a new item and $O_x$ denotes an old item from position $x$ in the study list. The lag between two successive old items ($\ldots O_i$, $O_j \ldots$) is just the distance, $j - i$, between the items on their initial presentation.

Suppose that recognition of a test item, $O_i$, brings forth the mental state – or temporal context – that prevailed when $O_i$ was first encoded. Suppose further

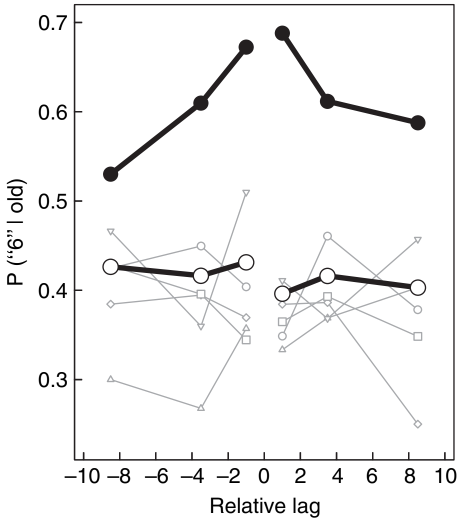


**Figure 8** Contiguity effects in item recognition are specific to highest-confidence responses. Probability of a highest confidence (6) response to an old-item test probe as a joint function the relative lag of, and the response given to, the preceding old-item probe. Large filled circles represent 6 responses to the prior test probe. Open symbols represent one of the other five possible prior responses; downward-facing triangles, boxes, triangles, upward-facing diamonds, and circles represent responses 1–5 respectively. Large open circles collapse data over responses 1–5. Data are from Schwartz et al. (2005). Shadows of the past: Temporal retrieval effects in recognition memory. *Psychol. Sci.* 16: 898–904.

that this retrieved mental state contributes to the retrieval environment that determines subsequent recognition judgments. Then, if the very next test item is $O_j$, we would predict that memory for $O_j$ should be enhanced when lag $= j - i$ is near zero.

The data in **Figure 8** show that when two old items are tested successively, memory for the second is better if it was initially presented in temporal proximity to the first. This tendency, however, was wholly attributable to cases in which the first item received a highest-confidence response. These highest-confidence old responses may be considered to reflect successful recollection of specific attributes of the encoding episode, whereas lower-confidence old responses are assumed to reflect the familiarity of an item whose attributes are not recollected (Yonelinas, 1999; Sherman et al., 2003). Schwartz et al. (2005)'s observation of contiguity effects in item recognition suggests that recollection of an item not only retrieves detailed information about the item tested, but also retrieves information about the item's neighbors.

We have now seen that the contiguity effect appears in all of the major episodic memory paradigms, including free recall, serial recall, probed recall, paired-associates, and even item recognition. The ubiquitous nature of this phenomenon implores us to search for an explanation in terms of fundamental principles of memory function. This search is the topic of the next section.

## 2.26.5 Theories of Episodic Association

Four major theories have been proposed to account for associative processes in episodic memory: (1) associative chaining, (2) associations formed in working memory (or buffer theory), (3) hierarchical associations (or chunking theory), and (4) contextual retrieval theory. In this section, we examine the implications of each of these four theories for the key empirical findings concerning contiguity-based associations in episodic memory.

Chaining theory, which originates in the writings of the associationists (e.g., Herbart, 1834) and in the early experimental work of Ebbinghaus, (1885/1913), assumes that when the memorial representations of two items become simultaneously active, or become active in rapid succession, the items' representations become associated in the sense that activation of one will evoke the other. A key feature of chaining is that associations are formed on the basis of temporal contiguity at study and that an item's representation is assumed to remain active only until the occurrence of the next item in the list.

Buffer models elaborate the basic chaining idea to include a mechanism that maintains an item's representations in the system past its actual presentation, allowing direct interitem associations to be created between items that are presented further apart in time (remote associations). Whereas classic chaining models assume that only two items are simultaneously active, buffer models allow for a larger number of items to be maintained in an active state and provide rules that determine when an item enters and leaves the active state (i.e., the buffer; Raaijmakers and Shiffrin, 1981).

Hierarchical associative models are based on the idea that multiple items can become unitized into a higher-order, conjunctive, representation which is distinct from any of the constituent items. These models have been particularly useful in describing the process of serial learning and serial recall (Johnson, 1972; Martin and Noreen, 1974; Lee and Estes, 1977; Murdock, 1995b, 1997). They assume that associations between items are mediated by a higher-level (super-ordinate) representation.

Finally, contextual retrieval theory assumes that items are associated with a time-varying representation of spatiotemporal/situational context (Estes, 1955; Bower, 1972; Burgess and Hitch, 2005). Successively presented items are associated with this context representation, which then can be used as a cue to retrieve those item representations during the recall period. Importantly, associations arise when items retrieve their encoding context, which in turn cues neighboring items (Howard and Kahana, 2002).

Although we consider each of these major theories in turn, they are not mutually exclusive. In some cases, modern theories of episodic memory make use of more than one of the ideas presented above. For example, some modern buffer models also use a representation of temporal context to differentiate items on the current target list from items on previous lists (Mensink and Raaijmakers, 1988; Sirotin et al., 2005).

As we see it, any theory of associative memory retrieval needs to account for (at least) seven critical behavioral findings regarding temporal-associative processes. The first of these is the contiguity effect – the tendency for neighboring items to be recalled successively. The second critical finding is the asymmetry effect – the tendency for subjects to make transitions to items studied in subsequent list positions. This forward asymmetry is remarkably robust in free recall, being observed in every dataset that reports output order effects. The third critical finding is the long-range contiguity effect – the observation of contiguity effects in continuous-distraction free recall and in a final free-recall task. This finding illustrates how episodic associations are not limited to successively studied items, or even to items studied within a short time period. Rather, contiguity-based associations appear to span many intervening items. The fourth critical finding is that when items are repeated across lists, prior-list intrusions in free recall tend to come from serial positions close to the original presentation (Zaromb et al., 2006). This illustrates the tendency for associations formed on prior lists to influence memory for the current list. Fifth, the tendency for intrusions in serial-recall and probed-recall paradigms is to come from list positions close to the target item. This tendency also exhibits a forward asymmetry effect, where errors tend to be items from subsequent list positions. Sixth, the tendency is for intrusions in paired-associate paradigms to come from neighboring pairs. Although this effect exhibits some forward asymmetry, memory for the items within a pair is strikingly symmetric, with recall accuracy being nearly identical for forward and backward probes (Ekstrand, 1966; Kahana, 2002). Finally, the seventh critical finding is the observation of a contiguity effect in an item recognition task (though this effect appears to be limited to probe items that receive highest confidence old responses). In the sections below, we review the ability of the four major theories of episodic association to account for these findings.

In addition to the temporally defined associative processes reviewed above, a parallel set of findings concerns recency-sensitive processes in memory retrieval. Murdock (1974) summarizes the literature on primacy and recency effects in immediate recall and recognition tasks. Briefly, recency is the most prominent feature of the serial position curves obtained in free recall, paired-associate recall, probed recall, and item recognition. In serial recall, the primacy effect is more prominent than the recency effect. This is largely due to the fact that serial recall requires that subjects initiate recall at the start of the list. Although within-list recency effects in recall tasks are largely attenuated by an end-of-list distractor, recency returns in continuous-distractor free recall (Bjork and Whitten, 1974; Glenberg et al., 1980; Howard and Kahana, 1999). Recency is also observed over much longer time scales than the presentation of a single list, as evidenced by the observation that prior-list intrusions tend to come from recent lists (Murdock, 1974; Zaromb et al., 2006). Similarly, on a final free recall test, subjects are far more likely to recall items from recently studied lists (Craik, 1970; Tzeng, 1973; Glenberg et al., 1980; Howard et al., 2008). Thus, any theory of episodic memory must be able to accommodate recency across very long time scales. Whereas immediate recency effects have often been attributed to the operation of a short-term store, or buffer, longer-range recency effects are often attributed to a contextual coding process. A critical question is whether these recency effects have a common basis or whether they arise from distinct mechanisms (Greene and Crowder, 1984; Raaijmakers, 1993; Davelaar et al., 2005).

### 2.26.5.1 Chaining Theory

According to early conceptualizations of chaining theory, studying an item leads to the creation or strengthening of forward and backward connections

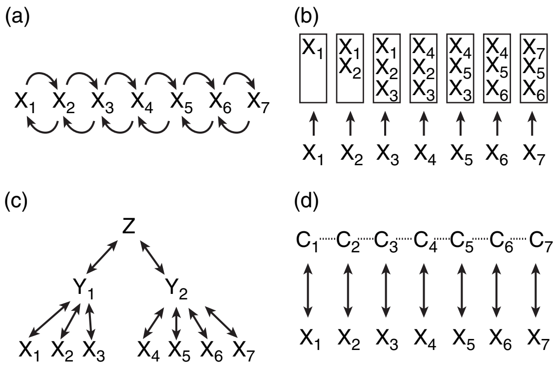


**Figure 9** Illustration of the four types of memory models. (a) Chaining Theory. Each item is associated with its immediate neighbors. (b) Buffer Theory. Items are inserted into a fixed-capacity buffer and reside there until displaced. (c) Hierarchical Association Theory. Conjunctions of items are used to create higher-level representations, which are associated with the original items. (d) Contextual Retrieval Theory. A slowly changing context representation is associated with each of the items.

to the immediately preceding item, with associations being stronger in the forward direction (**Figure 9(a)**). As this classic version of chaining theory has often been associated with behaviorism and its rejection of mentalistic constructs, chaining has been a frequent source of ridicule at the hands of cognitively oriented theorists.

Modern chaining theories (e.g., Lewandowsky and Murdock, 1989; Chance and Kahana, 1997) improve on earlier conceptualizations in a number of critical ways. First, modern chaining theories represent each item as a collection of abstract features or attributes rather than as a single node. Second, associations are conceptualized as networks of connections between the processing units that represent the attribute values. These associative networks can be seen as representing a new entity rather than simply linking two preexisting knowledge structures. The associative retrieval process is thus able to recover a partial representation of an item and use that representation as a cue for subsequent recalls. In addition, the attribute representation of items provides a natural way of characterizing the similarities among item representations. By capturing the similarities among items, chaining models can simulate critical aspects of the behavioral data, such as the effect of semantic similarity on recall.

Lewandowsky and Murdock (1989) used the mathematical operations of convolution and correlation to simulate the chaining of associations among item representations in memory. This mathematical approach has also been used by Murdock and his colleagues to simulate data on free recall (Metcalfe and Murdock, 1981), paired associates, and item recognition (Murdock, 1982, 1992). Similar models have also been developed using Hebbian weight matrices to store associations (Humphreys et al., 1989; Rizzuto and Kahana, 2001; Kahana et al., 2005b).

**Table 1** illustrates chaining theory's predictions regarding the seven critical findings reviewed above. It is not surprising that chaining theory predicts a contiguity effect in both immediate and delayed free recall (Kahana, 1996). Although most theories do not make explicit accounts of latency, it would be relatively straightforward to model the effect of contiguity on latency by using the strength of association to drive a diffusion model (e.g., Ratcliff, 1978).

Chaining theory is consistent with the idea that associations learned on earlier lists can induce subjects to commit intrusions when those earlier items are repeated in the target list. Further, when intrusions beget intrusions, chaining theory predicts that those intrusions should exhibit similar contiguity effects within the prior list that they came from (Zaromb et al., 2006). However, to accurately simulate the relatively modest interlist effects observed in the data, chaining theory must be augmented with a list context representation that is used to focus retrieval on the items in the target list (e.g., Sirotin et al., 2005).

Chaining theory can accommodate the forward asymmetry of the contiguity effect by differentially weighting the storage of forward and backward associations. This is not easily accomplished within the convolution-correlation formalism of Murdock and colleagues, but it can be easily implemented in a Hebbian matrix model (Pike, 1984; Kahana, 2002). Even so, employing differential weighting of forward and backward associations does little to explain the phenomenon.

The standard version of chaining theory assumes that associations are forged among neighboring items. One can extend the standard chaining model to produce the gradient of remote associations seen in the contiguity-effect in free recall by modeling the rehearsal process. When presented with an item for study, subjects often think about that item in relation to recently studied items. This rehearsal process will cause the functional order of study to differ from the nominal order of presentation (Brodie and Murdock, 1977; Tan and Ward, 2000), resulting in the remote

**Table 1** The ability of four major theories of association to account for contiguity phenomena across memory tasks.

| Theory | Contiguity | Asymmetry | Long-range contiguity | Prior-list intrusions | Probed recall intrusions | Across-pair intrusions | Contiguity in item recognition |
|---|---|---|---|---|---|---|---|
| Chain | ✓ | * | × | ✓ | ✓ | ✓ | * |
| Buffer | ✓ | * | × | ✓ | ✓ | ✓ | * |
| Vertical | ✓ | * | × | ✓ | ✓ | * | * |
| Context | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

The ✓ symbol means that the model can account for the data without modification. The * symbol means that the model requires some modification from the standard version to account for this data-point (see text for elaboration of each case). The × symbol means that the model is unable to account for this data-point.

associations of the kind seen in Figure 2(a). The standard approach to modeling rehearsal in free recall is to assume that rehearsal is controlled by a working memory buffer that actively maintains (and rehearses) a small number of items (e.g., Raaijmakers and Shiffrin, 1980). We discuss the predictions of these so-called buffer models in the next subsection.

The more serious challenge to chaining theory comes from the observation of preserved long-range contiguity effects in free recall. It is hard to envision how chaining models would explain the approximate time-scale invariance of the contiguity effect, as shown in Figure 5(b). Nearest-neighbor chaining theory, even when augmented with a rehearsal buffer and a list-context representation, would predict a diminished contiguity effect when subjects perform a demanding distractor task following each study item. For chaining theory to explain the long-range contiguity effect in continuous-distractor free recall, one would have to assume that remote associations extend through distractor intervals and even across entire lists. To explain the gradient of intrusions observed in recall of paired-associates (Figure 7(c)), one would need to assume that remote associations automatically link items that were studied in nonadjacent pairs.

The finding of associative effects in item recognition is also not easily explained by chaining theory, as it would require associations to be automatically formed between items even when there is no task demand to do so. If chained associations were automatically formed between neighboring items, and if compound cueing operates at retrieval (e.g., McKoon and Ratcliff, 1992), then chaining theory should be able to predict the associative effects seen in Figure 8.

It would be misleading to imply that chaining theory should be evaluated solely on the basis of the select phenomena highlighted in Table 1. In the domain of serial recall, where chaining theories have been most thoroughly investigated, the basic chaining model offers strikingly counterfactual predictions concerning subjects' recall errors, particularly in lists that incorporate repetitions of identical or similar items (Ranschburg, 1902; Lashley, 1951; Crowder and Melton, 1965; Crowder, 1968; Henson et al., 1996; Henson, 1998; Kahana and Jacobs, 2000).

### 2.26.5.2 Working Memory Buffers and Dual Store Theory

Chaining theory makes the implicit assumption that the just-presented item is somehow maintained long enough to become associated with the current item. In essence, the just-presented item must be maintained in some type of working memory buffer. Dual-store memory models, such as the Atkinson–Shiffrin model and its more modern descendant, the SAM retrieval model, elevate the working memory buffer to a far more prominent role (Raaijmakers and Shiffrin, 1980; Sirotin et al., 2005). These models assume a working memory buffer that is capable of holding multiple items during list presentation. Any items residing in the buffer at the time of test may be recalled without a lengthy search process. Moreover, the rules that determine how items enter and leave the buffer can be designed to simulate the process of strategic rehearsal, thus enabling the models to account for aspects of free-recall data that are believed to depend on the pattern of rehearsals that occur during list presentation (Rundus, 1971; Brodie and Murdock, 1977; Tan and Ward, 2000; Laming, 2006). The critical assumption for our purposes is that items that are co-resident in the buffer become associated, and the size of the buffer determines the range of remote associations among items (see Figure 9(b)).

The SAM retrieval model, and its latest variant, eSAM, offers the most comprehensive model of free recall currently available (Raaijmakers and Shiffrin, 1980; Sirotin et al., 2005). The model's ability to explain a wide range of data, including findings concerning semantic organization effects, comes at the expense of a greater number of assumptions and mechanisms that are built into the model. For example, the eSAM model incorporates associations between items that share time in the buffer (essentially chaining) as well as associations between a time-varying list context signal and items. These associations reside in an episodic memory matrix that is distinct from a semantic memory matrix which is also used in retrieval. eSAM (and SAM) include a dynamical probabilistic recall process which keeps track of which items have already been recalled given a particular set of cues. Finally, a postretrieval recognition test is used to determine whether a retrieved item should be recalled or rejected due to its weak strength to the current list context.

It is important to note that buffer models such as those described by Davelaar et al. (2005) and Sirotin et al. (2005) have been shown to account for a very wide range of recall phenomena. For example, buffer models provide a natural explanation for the striking recency effect observed in immediate free recall and its marked attenuation following a brief interval of distracting activity. Because retrieval of items remaining in the buffer produces the recency effect in immediate recall tasks, buffer-based models can also neatly explain the numerous dissociations between recall of recency and prerecency items, as well as dissociations between immediate and continuous distractor free recall (Davelaar et al., 2005). Although they cannot easily account for long-range contiguity effects, buffer models still represent an important benchmark in the episodic memory literature.

### 2.26.5.3 Hierarchical Association Theory

Hierarchical models of association (e.g., Johnson, 1972; Lee and Estes, 1977; Murdock, 1995a, 1997; Anderson and Matessa, 1997; Anderson et al., 1998) attempt to explain how subjects unitize (or chunk) groups of items to create new conjunctive representations in memory. Whereas both chaining and buffer models define associations as directly linking neighboring items, hierarchical models assume that associations are mediated by a superordinate representation that provides access to two or more neighboring items. An item can be used to retrieve the superordinate representation (or chunk) which in turn can retrieve the other items associated with it. This kind of hierarchical associative structure is illustrated in **Figure 9(c)**.

Hierarchical theories of association have been largely motivated by the observation that practiced subjects tend to rhythmically group items during serial learning (e.g., Müller and Pilzecker, 1900). Because it is difficult to study subjects' grouping strategies in an unconstrained learning situation, researchers have devised methods to encourage specific grouping strategies whose consequences can be reliably measured. Such experimenter-imposed grouping is typically achieved by inserting pauses at regular intervals during list presentation.

There are four major consequences of experimenter-imposed grouping. First, consistent grouping leads to better serial recall, with the highest levels of recall observed for group sizes of three or four items (Wickelgren, 1967). Second, the grouping effect is largest for auditorally presented lists (Ryan, 1969). Third, grouping leads subjects to recall items in the correct within-group position but in the wrong group (Johnson, 1972; Brown et al., 2000). Fourth, subjects inter-response times during recall are longer at group boundaries (Maybery et al., 2002). These and related findings inspired the development of hierarchical associative models which have been applied with great success to data on serial recall (e.g., Estes, 1972; Lee and Estes, 1977; Murdock, 1993, 1997).

Hierarchical, or vertical, associations can be used to create representations that bridge time, which would help to explain some of the critical findings listed in **Table 1**. If the model is able to make a higher-level bridging representation associating successively presented items, then it can capture the contiguity effect. It is less clear whether a model like this can capture the asymmetry effect (Murdock, 1995b). Long-range contiguity effects pose a greater challenge, as they would require hierarchical representations to be robust to distraction, and to keep building up across lists. Hierarchical associations may be able to capture the contiguity effect in recognition, but this would require that the hierarchical representations are formed when there is no task demand to do so.

The preceding discussion refers to a type of hierarchical representation that bridges representations that are separated in time; however, another class of hierarchical models forms higher-level representations that bridge various simultaneously active lower-level representations. In particular, the connectionist model of episodic memory introduced by McClelland et al. (1995), and further developed by Norman and O'Reilly (2003) posits that the hippocampus serves as the locus of a higher-level representation that represents the conjunction of all of the features activated in the various cortical areas that project to it. This hippocampally based episodic representation is associated with all of these lower-level features such that the later activation of a subset of those features allows the episodic representation to be retrieved; it then projects out to the cortical areas and reactivates the full set of originally active features.

### 2.26.5.4 Contextual Retrieval Theory

The effective use of memory depends on our ability to focus retrieval on those memories learned within a given spatiotemporal context (e.g., Carr, 1931; McGeoch, 1932). According to temporal-context models, the memory system associates each studied item with the contextual features present at the time of encoding. At the time of test, the current state of context is a good retrieval cue for recently studied memories (Bower, 1972; Howard and Kahana, 2002). Because retrieval results from a competition among activated memory traces, one observes recency both in immediate and in continuous-distractor free recall (Bjork and Whitten, 1974; Crowder, 1976; Howard and Kahana, 1999).

Howard and Kahana (2002) proposed an extension of the classic Estes-Bower context theory that was designed to explain the observation of long-range contiguity effects. According to their temporal context model (TCM), recall of an item results in a partial reinstatement of the context that was present when that item was studied. This retrieved context then serves as a retrieval cue for other items with a similar context at study, which are most likely to be items from nearby serial positions, thus yielding the contiguity effect.

TCM provides a natural explanation for the robust contiguity effects found in continuous-distractor free recall, as retrieval transitions are driven by the relative similarity between the temporal contexts of different list items. As long as a similar duration of distracting activity separates each item from its neighbors, TCM predicts that the transitions among neighboring list items will be largely independent of the absolute temporal separation of the items in the list.

According to TCM, context is a vector that changes gradually as a result of items being activated in semantic memory. TCM provides a formal mathematical model of how temporal context evolves as a consequence of item encoding and retrieval. It also describes an associative architecture, implemented as a neural network, that links both items to context and context to items.

A given state of temporal context will cue recall items via the context-to-item associative network. Consistent with Tulving's notion of encoding specificity (Tulving, 1983), the optimal cue for an item is the context in which it was encoded. Because context changes gradually, the state of context at the time of test will overlap most strongly with the contexts associated with recent items. This gives rise to the recency effect seen in all episodic memory tasks. Primacy is accommodated within TCM by assuming that early list items receive more rehearsals and/or increased attentional resources (Brodie and Murdock, 1977; Tan and Ward, 2000).

Just as contextual states can retrieve items in semantic memory, so too can items retrieve their associated contextual states. In TCM, it is this process of contextual reactivation that drives the evolution of the context vector itself. Contiguity effects arise because the retrieved contextual states overlap with the encoding context of nearby items. For a more complete treatment, the reader is referred to Howard and Kahana (2002) and Howard et al. (2006). For a discussion of a potential mapping between TCM and the structure and function of the medial temporal lobe, see Howard et al. (2005).

According to TCM, the forward-bias in the contiguity effect arises because recall of an item retrieves both the context stored during list presentation (which is similar to both the prior and subsequent list items) and the pre-experimental contextual states associated with the item. Because the pre-experimental contextual states associated with an item is added to the context vector at the time of the item's encoding, that part of the retrieved context is similar to the contextual states associated with subsequent list items but not prior list items. Thus, the context retrieved by an item includes a symmetric component (the contextual state associated during list presentation) and an asymmetrical component (the pre-experimental contextual states). The combination of these two components produces the forward asymmetry seen in the contiguity effect (**Figure 2(a)**).

Retrieved context is one way that contiguity effects could arise across wide-ranging time scales, such as those observed in continuous-distractor free recall, final free recall, and recall of paired-associates. Dennis and Humphreys (2001) suggested that temporal context may underlie recognition judgments as well. In this case, one might predict that high confidence yes responses reflect successful retrieval of context. The contiguity effect seen in item recognition (Figure 8) could arise if the retrieved contextual representation of an item combined with the subsequent test probe.

## 2.26.6 Conclusions and Open Questions

The evidence we have reviewed shows how retrieval of episodic memories is a cue-dependent process that reflects the temporal contiguity and the semantic relatedness of the cue and the target items. Analyses of retrieval transitions in free recall demonstrate that both temporal and semantic factors have a dramatic effect on retrieval. Although subjects may recall items in any order they wish, the recall of a given item is predictable on the basis of its semantic relatedness and temporal contiguity to the just recalled item.

The contiguity effect, as seen in Figure 2(a), exhibits a strong forward asymmetry, with recall transitions being nearly twice as likely in the forward than in the backward direction. This tendency to make forward transitions contrasts with the overall tendency to begin recall at the end of the list (Kahana, 1996). Contiguity and asymmetry are ubiquitious in free recall. The basic lag-CRP and lag-CRL curves have the same form for lists of different lengths and presentation rates, for different presentation modalities, for different word frequencies, etc. Although reduced for older adults, the contiguity and asymmetry effects have the same basic form across age groups.

The contiguity effect is not limited to free recall; rather, it is a nearly universal characteristic of retrieval in episodic memory. Contiguity is seen in the pattern of correct recalls, inter-response times, and intrusions in free recall, and in the memory errors seen in probed recall, serial recall, and paired-associate recall. Even in item recognition, contiguity appears when subjects respond with high confidence.

One of the most striking and theoretically significant features of the contiguity effect is its persistence across time scales. In free recall, the contiguity effect is not reduced when list items are separated by 16 s of distractor activity. In recall of paired associates, contiguity appears in subjects' tendency to recall items from nearby pairs, thus demonstrating that contiguity does not depend on subjects intention to learn the association between neighboring items.

Four major theories have been proposed to explain episodic associations: Chaining theory, buffer theory, hierarchical association theory, and retrieved context theory. Whereas all of these theories can account for the basic contiguity effect, retrieved context theory offers the only adequate account of the long-range contiguity effect. Retrieved context theories, such as TCM, provide a basis for synthesizing the associative effects observed across all of the major episodic recall and recognition paradigms. In TCM, associative effects appear because retrieved context of a given item overlaps with the encoding context of nearby items. This approach constitutes a departure from traditional accounts of association, such as those assuming direct interitem associations (chaining or buffer theory) or those that assume hierarchial associative structures.

Although the presence of contiguity across time scales supports the contextual retrieval account of episodic association, it does not preclude the operation of other factors as suggested by the alternative theories. For example, it is possible to envision a hierarchical associative model or a buffer-based associative model that also includes a contextual retrieval mechanism.

Despite the enormous strides in our understanding of episodic association, a number of intriguing puzzles remain to be solved. One unsolved puzzle concerns the asymmetric nature of episodic associations. Although the forward asymmetry is a striking feature of associations in free recall, serial recall, and probed recall, the data do not reveal striking asymmetries in all episodic tasks. Moreover, recall of individual paired associates is almost perfectly symmetrical, with subjects exhibiting nearly identical rates of forward and backward recall, and with forward and backward recall being highly correlated at the level of individual pairs (Kahana, 2002).

Perhaps the most important of these puzzles is the question of how the rich structure of semantic associations in human memory could arise simply due to the repeated presentation of related items in temporal proximity. Computational models of semantic memory, such as LSA (Landauer and Dumais, 1997) and the topics model (Griffiths and Steyvers, 2002, 2003) provide some clues as to how such a reconciliation might be possible. LSA and the topics model extract information about the temporal contexts in which words appear to estimate their meaning. Specifically, in these models, temporal context is defined as a passage of text. The hyperspace analog of language (HAL, Lund and Burgess, 1996) and BEAGLE (Jones and Mewhort, 2007) models define temporal context as a sliding window of a fixed number of words. This suggests the possibility of a unification of computational models of semantic memory and models of episodic memory based on contextual retrieval (Dennis and Humphreys, 2001; Howard and Kahana, 2002), in that each process may rely on the presence of a slowly-drifting source of contextual information.

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## References

Anderson JR and Matessa M (1997) A production system theory of serial memory. *Psychol. Rev.* 104: 728–748.
Anderson JR, Bothell D, Lebiere C, and Matessa M (1998) An integrated theory of list memory. *J. Mem. Lang.* 38: 341–380.
Asch SE and Ebenholtz SM (1962) The principle of associative symmetry. *Proc. Am. Philos. Soc.* 106: 135–163.
Atkinson RC and Shiffrin RM (1968) Human memory: A proposed system and its control processes. In: Spence KW and Spence JT (eds.) *The Psychology of Learning and Motivation,* Vol. 2, pp. 89–105. New York: Academic Press.
Bjork RA and Whitten WB (1974) Recency-sensitive retrieval processes in long-term free recall. *Cogn. Psychol.* 6: 173–189.
Bousfield WA (1953) The occurrence of clustering in the recall of randomly arranged associates. *J. Gen. Psychol.* 49: 229–240.
Bousfield WA, Sedgewick CH, and Cohen BH (1954) Certain temporal characteristics of the recall of verbal associates. *Am. J. Psychol.* 67: 111–118.
Bower G (1967) A multicomponent theory of the memory trace. In: Spence KW and Spence JT (eds.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* Vol. 1, pp. 229–325. New York: Academic Press.
Bower GH (1972) Stimulus-sampling theory of encoding variability. In: Melton AW and Martin E (eds.) *Coding Processes in Human Memory*, pp. 85–121. New York: John Wiley and Sons.
Brodie DA and Murdock BB (1977) Effects of presentation time on nominal and functional serial position curves in free recall. *J. Verb. Learn. Verb. Behav.,* 16: 185–200.
Brown GDA, Preece T, and Hulme C (2000) Oscillator-based memory for serial order. *Psychol. Rev.,* 107(1): 127–181.
Burgess N and Hitch G (2005) Computational models of working memory: putting long-term memory into context. *tics,* 9: 535–41.
Caplan JB, Glaholt M, and McIntosh AR (2006) Linking associative and list memory: pairs versus triples. *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 1244–1265.
Carr HA (1931) The laws of association. *Psychol. Rev.* 38: 212–228.
Chance FS and Kahana MJ (1997) Testing the role of associative interference and compound cues in sequence memory. In: Bower J. (ed.) *Computational Neuroscience: Trends in Research*, pp. 599–603. New York: Plenum Press.
Craik FIM (1970) The fate of primary memory items in free recall. *J. Verb. Learn. Verb. Behav.,* 9: 658–664.
Craik FIM and Levy BA (1970) Semantic and acoustic information in primary memory. *J. Exp. Psychol.* 86: 77–82.
Crowder RG (1968) Intraserial repetition effects in immediate memory. *J. Verb. Learn. Verb. Behav.,* 7: 446–451.
Crowder RG (1976) *Principles of Learning and Memory*. Hillsdale, NJ: Lawrence Erlbaum and Associates.
Crowder RG and Melton AW (1965) The Ranschburg phenomenon: Failures of immediate recall correlated with repetition of elements within a stimulus. *Psychon. Sci.* 2: 295–296.
Davelaar EJ, Goshen-Gottstein Y, Ashkenazi A, Haarmann HJ, and Usher M (2005) The demise of short-term memory revisited: Empirical and computational investigations of recency effects. *Psychol. Rev.* 112: 3–42.
Davis OC, Geller AS, Rizzuto DS, and Kahana MJ (2008) Temporal associative processes revealed by intrusions in paired-associate recall. *Psychon. Bull. Rev.* 15(1): 64–69.
Deese J (1959) On the prediction of occurrence of particular verbal intrusions in immediate recall. *J. Exp. Psychol.* 58: 17–22.
Deese J and Kaufman RA (1957) Serial effects in recall of unorganized and sequentially organized verbal material. *J. Exp. Psychol.* 54: 180–187.
Dennis S and Humphreys MS (2001) A context noise model of episodic word recognition. *Psychol. Rev.* 108: 452–478.
Ebbinghaus H (1885/1913) *On Memory: A Contribution to Experimental Psychology*. New York: Teachers College, Columbia University.
Ekstrand BR (1966) Backward associations. *Psychol. Bull.* 65: 50–64.
Estes WK (1955) Statistical theory of spontaneous recovery and regression. *Psychol. Rev.* 62: 145–154.
Estes WK (1972) An associative basis for coding and organization in memory. In: Melton AW and Martin E (eds.) *Coding Processes in Human Memory*, pp. 161–190. Washington, DC: Winston.
Gallo DA and Roediger HL (2002) Variability among word lists in eliciting memory illusions: Evidence for associative activation and monitoring. *J. Mem. Lang.* 47: 469–497.
Gillund G and Shiffrin RM (1984) A retrieval model for both recognition and recall. *Psychol. Rev.* 91: 1–67.
Giurintano SL (1973) Serial learning process: test of chaining, position, and dual process hypotheses. *J. Exp. Psychol.* 97(2): 154–157.
Glanzer M (1972) Storage mechanisms in recall. In: Spence KW. and Spence JT. (eds.) *The Psychology of Learning and Motivation*, pp. 129–193. New York: Academic Press.
Glanzer M and Cunitz AR (1966) Two storage mechanisms in free recall. *J. Verb. Learn. Verb. Behav.* 5: 351–360.
Glenberg AM, Bradley MM, Stevenson JA, Kraus TA, Tkachuk MJ, and Gretz AL (1980) A two-process account of long-term serial position effects. *J. Exp. Psychol. Learn. Mem. Cogn.* 6: 355–369.
Glenberg AM, Bradley MM, Kraus TA, and Renzaglia GJ (1983) Studies of the long-term recency effect: Support for a contextually guided retrieval theory. *J. Exp. Psychol. Learn. Mem. Cogn.* 12: 413–418.
Greene RL and Crowder RG (1984) Effects of semantic similarity on long-term recency. *Am. J. Psychol.* 97: 441–449.

Griffiths T and Steyvers M (2002) A probabilistic approach to semantic representation. *Proceedings of the 24th Annual Conference of the Cognitive Science Society*.

Griffiths T and Steyvers M (2003) Prediction and semantic association. In: Halmberg KJ and Steyvers M (eds.) *Advances in Neural Information Processing Systems, 15*, pp. 11–18. Cambridge, MA: MIT Press.

Henson RNA (1998) Item repetition in short-term memory: Ranschburg repeated. *J. Exp. Psychol. Learn. Mem. Cogn.* 24: 1162–1181.

Henson RNA, Norris DG, Page MPA, and Baddeley AD (1996) Unchained memory: Error patterns rule out chaining models of immediate serial recall. *Q. J. Exp. Psychol.* 49A: 80–115.

Herbart JF (1834) Lehrbuch zur Psychologie. In: Kehrbach K (ed.) pp. 376–377. Konigsberg: August Wilhelm Unzer.

Hogan RM (1975) Interitem encoding and directed search in free recall. *Mem. Cognit.* 3: 197–209.

Hollingsworth HL (1928) *Psychology: Its Facts and Principles*. D. Appleton and Company.

Howard MW and Kahana MJ (1999) Contextual variability and serial position effects in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 923–941.

Howard MW and Kahana MJ (2002) A distributed representation of temporal context. *J. Math. Psychol.* 46: 269–299.

Howard MW, Fotedar MS, Datey AV, and Hasselmo ME (2005) The temporal context model in spatial navigation and relational learning: Toward a common explanation of medial temporal lobe function across domains. *Psychol. Rev.* 112(1): 75–116.

Howard MW, Kahana MJ, and Wingfield A (2006) Aging and contextual binding: modeling recency and lag recency effects with the temporal context model. *Psychon. Bull. Rev.* 13: 439–445.

Howard MW, Addis KA, Jing B, and Kahana MJ (2007) Semantic structure and episodic memory. Invited chapter for *LSA*: *A Road Towards Meaning*, T. Landauer, D. McNamara, S. Dennis, and W. Kintsch (eds), Laurence Erlbaum, pp. 121–141.

Howard MW, Youker TE, and Venkatadass V (2008) The persistence of memory: Contiguity effect across several minutes. *Psychon. Bull Rev.* 15: 58–63.

Hoyer WJ and Verhaeghen P (2006) Memory aging. In: Birren JE and Schaie KW (eds.) *Handbook of the Psychology of Aging (6th edition)*, pp. 209–232. San Diego: Elsevier.

Humphreys MS (1978) Item and relational information: A case for context independent retrieval. *J. Verb. Learn. Verb. Behav.* 17: 175–187.

Humphreys MS, Bain JD, and Pike R (1989) Different ways to cue a coherent memory system: A theory for episodic, semantic, and procedural tasks. *Psychol. Rev.* 96: 208–233.

Hunt RR and McDaniel MA (1993) The enigma of organization and distinctiveness. *J. Mem. Lang.* 32(4): 421–445 Aug.

Johnson NF (1972) Organization and the concept of a memory code. In: Melton AW. and Martin E. (eds.) *Coding Processes in Human Memory*, pp. 125–159. Washington, DC: Winston.

Jones MN and Mewhort DJK (2007) Representing word meaning and order information in a composite holographic lexicon. *Psychol. Rev.* 114: 1–37.

Kahana MJ (1996) Associative retrieval processes in free recall. *Mem. Cognit.* 24: 103–109.

Kahana MJ (2002) Associative symmetry and memory theory. *Mem. Cognit.* 30: 823–840.

Kahana MJ and Caplan JB (2002) Associative asymmetry in probed recall of serial lists. *Mem. Cognit.* 30: 841–849.

Kahana MJ and Howard MW (2005) Spacing and lag effects in free recall of pure lists. *Psychon. Bull. Rev.* 12: 159–164.

Kahana MJ and Jacobs J (2000) Inter-response times in serial recall: Effects of intraserial repetition. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1188–1197.

Kahana MJ and Loftus G (1999) Response time versus accuracy in human memory. In: Sternberg RJ (ed.) *The Nature of Cognition*, pp. 322–384. Cambridge, MA: MIT Press.

Kahana MJ, Howard MW, Zaromb F, and Wingfield A (2002) Age dissociates recency and lag recency effects in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 28: 530–540.

Kahana MJ, Dolan ED, Sauder CL, and Wingfield A (2005a) Intrusions in episodic recall: Age differences in editing of overt responses. *J. Gerontol. Psychol. Sci.* 60: 92–97.

Kahana MJ, Rizzuto DS, and Schneider A (2005b) Theoretical correlations and measured correlations: Relating recognition and recall in four distributed memory models. *J. Exp. Psychol. Learn. Mem. Cogn.* 31: 933–953.

Kausler DH (1994) *Learning and memory in normal aging*. San Diego, CA: Academic Press.

Kimball DR and Bjork RA (2002) Influences of intentional and unintentional forgetting on false memories. *J. Exp. Psychol. Gen.* 131: 116–130.

Kinsbourne M and George J (1974) The mechanism of the word-frequency effect on recognition memory. *J. Verb. Learn. Verb. Behav.* 13: 63–69.

Kirkpatrick EA (1894 November) An experimental study of memory. *Psychol. Rev.* 1(6:): 602–609.

Klein KA, Addis KM, and Kahana MJ (2005) A comparative analysis of serial and free recall. *Mem. Cognit.* 33: 833–839.

Köhler W (1947) *Gestalt Psychology*. New York: Liveright.

Laming D (1999) Testing the idea of distinct storage mechanisms in memory. *Int. J. Psychol.* 34: 419–426.

Laming D (2006) Predicting free recalls. *J. Exp. Psychol. Learn. Mem. Cogn.* 32(5): 1146–1163.

Landauer TK and Dumais ST (1997) Solution to Plato's problem: The latent semantic analysis theory of acquisition, induction, and representation of knowledge. *Psychol. Rev.* 104: 211–240.

Lashley KS (1951) The problem of serial order in behavior. In: Jeffress LA (ed.) *Cerebral Mechanisms in Behavior*, pp. 112–136. New York: Wiley.

Lee CL and Estes WK (1977) Order and position in primary memory for letter strings. *J. Verb. Learn. Verb. Behav.* 16: 395–418.

Lewandowsky S and Murdock BB (1989) Memory for serial order. *Psychol. Rev.* 96: 25–57.

Loftus GR and Masson MEJ (1994) Using confidence intervals in within-subject designs. *Psychon. Bull. Rev.* 1: 476–490.

Lund K and Burgess C (1996) Producing high-dimensional semantic spaces from lexical co-occurrence. *Behav. Res. Methods Instrum. Comput.* 28(2): 203–208.

MacLeod CM and Kampe K (1996) Word frequency effects on recall, recognition, and word fragment completion tests. *J. Exp. Psychol.* 22(1): 132–142.

Martin E and Noreen DL (1974) Serial learning: Identification of subjective subsequences. *Cognit. Psychol.* 6: 421–435.

Maybery MT, Parmentier FBR, and Jones DM (2002) Grouping of list items reflected in the timing of recall: implications for models of serial verbal memory. *J. Mem. Lang.* 47: 360–385.

McClelland JL, McNaughton BL, and O'Reilly RC (1995) Why there are complementary learning systems in the hippocampus and neocortex: insights from the successes and failures of connectionist models of learning and memory. *Psychol. Rev.* 102(3): 419–57.

McGeoch JA (1932) Forgetting and the law of disuse. *Psychol. Rev.* 39: 352–70.

McGeoch JA and Irion AL (1952) *The Psychology of Human Learning*. 2nd edition. New York: Longmans, Green and Co.

McKoon G and Ratcliff R (1992) Spreading activation versus compound cue accounts of priming: Mediated priming revisited. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 1155–1172.

Mensink G-JM and Raaijmakers JGW (1988) A model for interference and forgetting. *Psychol. Rev.* 95: 434–455.

Metcalfe J and Murdock BB (1981) An encoding and retrieval model of single-trial free recall. *J. Verb. Learn. Verb. Behav.* 20: 161–189.
Müller GE and Pilzecker A (1900) Experimental contributions to memory theory. *Z. Psychol. Eganzungs.* 1: 1–300.
Murdock BB (1962) The serial position effect of free recall. *J. Exp. Psychol.* 64: 482–488.
Murdock BB (1968) Serial order effects in short-term memory. *J. Exp. Psychol. Monogr. Suppl.* 76: 1–15.
Murdock BB (1974) *Human Memory: Theory and Data*. Potomac, MD: Lawrence Erlbaum and Associates.
Murdock BB (1982) A theory for the storage and retrieval of item and associative information. *Psychol. Rev.* 89: 609–626.
Murdock BB (1992) Item and associative information in a distributed memory model. *J. Math. Psychol.* 36: 68–99.
Murdock BB (1993) TODAM2: A model for the storage and retrieval of item, associative, and serial-order information. *Psychol. Rev.* 100: 183–203.
Murdock BB (1995a) Developing TODAM: Three models for serial-order information. *Mem. Cognit.* 23: 631–645.
Murdock BB (1995b) Similarity in a distributed memory model. *J. Math. Psychol.* 39: 251–264.
Murdock BB (1997) Context and mediators in a theory of distributed associative memory (TODAM2). *Psychol. Rev.* 104: 839–862.
Murdock BB and Metcalfe J (1978) Controlled rehearsal in single- trial free recall. *J. Verb. Learn. Verb. Behav.* 17: 309–324.
Murdock BB and Okada R (1970) Interresponse times in single-trial free recall. *J. Verb. Learn. Verb. Behav.* 86: 263–267.
Murdock BB and Walker KD (1969) Modality effects in free recall. *J. Verb. Learn. Verb. Behav.* 8: 665–676.
Nairne JS (1990a) A feature model of immediate memory. *Mem. Cognit.* 18: 251–269.
Nairne JS (1990b) Similarity and long-term memory for order. *J. Mem. Lang.* 29: 733–746.
Naveh-Benjamin M (2000) Adult-age differences in memory performance: Tests of an associative deficit hypothesis. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1170–1187.
Neath I (1993) Contextual and distinctive processes and the serial position function. *J. Mem. Lang.* 32: 820–840.
Nelson DL, McEvoy CL, and Schreiber TA (2004) The University of South Florida free association, rhyme, and word fragment norms. *Behav. Res. Methods Instrum. Comput.* 36(3): 402–407.
Nilsson LG, Wright E, and Murdock BB (1975) The effects of visual presentation method on single-trial free recall. *Mem. Cognit.* 3: 427–433.
Norman KA and O'Reilly RC (2003) Modeling hippocampal and neocortical contributions to recognition memory: A complementary learning systems approach. *Psychol. Rev.* 110: 611–646.
Paivio A (1971) *Imagery and Verbal Processes*. New York: Holt, Rinehart, and Winston.
Pike R (1984) Comparison of convolution and matrix distributed memory systems for associative recall and recognition. *Psychol. Rev.* 91: 281–294.
Postman L and Phillips LW (1965) Short-term temporal changes in free recall. *Q. J. Exp. Psychol.* 17: 132–138.
Primoff E (1938) Backward and forward associations as an organizing act in serial and in paired-associate learning. *J. Psychol.* 5: 375–395.
Raaijmakers JGW (1993) The story of the two-store model of memory: Past criticisms, current status, and future directions. In: Meyer D. and Kornblum S. (eds.) *Attention and Performance xiv*, pp. 467–488. Cambridge MA: MIT Press.
Raaijmakers JGW and Shiffrin RM (1980) SAM: A theory of probabilistic search of associative memory. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* Vol. 14, pp. 207–262. New York: Academic Press.
Raaijmakers JGW and Shiffrin RM (1981) Search of associative memory. *Psychol. Rev.* 88: 93–134.
Ranschburg P (1902) Uber hemmung gleichzeitiger reizwirkungen. *Z. Psychol. Physiol. Sinnesorgane* 30: 39–86.
Raskin E and Cook SW (1937) The strength and direction of associations formed in the learning of nonsense syllables. *J. Exp. Psychol.* 20: 381–395.
Ratcliff R (1978) A theory of memory retrieval. *Psychol. Rev.* 85: 59–108.
Raymond BJ (1969) Short-term storage and long-term storage in free recall. *J. Verb. Learn. Verb. Behav.* 8: 567–574.
Rizzuto DS and Kahana MJ (2001) An autoassociative neural network model of paired-associate learning. *Neural Comput.* 13: 2075–2092.
Roberts WA (1972) Free recall of word lists varying in length and rate of presentation: A test of total-time hypotheses. *J. Exp. Psychol.* 92: 365–372.
Robinson ES (1932) *Association Theory Today; an Essay in Systematic Psychology*. New York: The Century Co.
Roediger HL and McDermott KB (1995) Creating false memories: Remembering words not presented in lists. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 803–814.
Roediger HL, McDermott KB, and Robinson KJ (1998) The role of associative processes in creating false memories. In: Conway M., Gathercole SE., and Cornoldi C. (eds.) *Theories of Memory,* vol. ii, pp. 230–241. New York: Psychology Press.
Rundus D (1971) An analysis of rehearsal processes in free recall. *J. Exp. Psychol.* 89: 63–77.
Ryan J (1969) Grouping and short-term memory: Different means and patterns of grouping. *Q. J. Exp. Psychol.* 21: 137–147.
Salthouse TA (1991) *Theoretical Perspectives on Cognitive Aging*. Hillsdale, NJ: Lawrence Erlbaum and Associates.
Schwartz G, Howard MW, Jing B, and Kahana MJ (2005) Shadows of the past: Temporal retrieval effects in recognition memory. *Psychol. Sci.* 16: 898–904.
Sherman SJ, Atri A, Hasselmo ME, Stern CE, and Howard MW (2003) Scopolamine impairs human recognition memory: Data and modeling. *Behav. Neurosci.* 117: 526–539.
Sirotin YB, Kimball DR, and Kahana MJ (2005) Going beyond a single list: Modeling the effects of prior experience on episodic free recall. *Psychon. Bull. Rev.* 12(5): 787–805.
Slamecka NJ (1987) The law of frequency. In: Gorfein DS and Hoffman RR (eds.) *Memory and Learning: The Ebbinghaus Centennial Conference*, pp. 105–128. Hillsdale, NJ: Lawrence Erlbaum and Associates.
Sommer T, Rose M, and Büchel C (2007) Associative symmetry versus independent associations in the memory for object-location associations. *J. Exp. Psychol. Learn. Mem. Cogn.* 33: 90–106.
Spiers HJ, Maguire EA, and Burgess N (2001) Hippocampal amnesia. *Neurocase* 7: 357–382.
Sternberg RJ and Tulving E (1977) The measurement of subjective organization in free recall. *Psychol. Bull.* 84(3): 539–556.
Steyvers M, Shiffrin RM, and Nelson DL (2004) Word association spaces for predicting semantic similarity effects in episodic memory. In: Healy AF (ed.) *Cognitive Psychology and its Applications: Festschrift in honor of Lyle Bourne, Walter Kintsch, and Thomas Landauer*, Washington, DC: American Psychological Association.
Sumby WH (1963) Word frequency and serial position effects. *J. Verb. Learn. Verb. Behav.* 1: 443–450.
Tan L and Ward G (2000) A recency-based account of the primary effect in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1589–1626.

Tulving E (1962) Subjective organization in free recall of ''unrelated'' words. *Psychol. Rev.* 69(4): 344–354.

Tulving E (1972) Episodic and semantic memory. In: Tulving E. and Donaldson W. (eds.) *Organization of Memory*, pp. 381–403. New York: Academic Press.

Tulving E (1983) *Elements of Episodic Memory*. New York: Oxford.

Tulving E and Madigan SA (1970) Memory and verbal learning. *Annu. Rev. Psychol.* 21: 437–484.

Tulving E and Thompson DM (1973) Encoding specificity and retrieval processes in episodic memory. *Psychol. Rev.* 80: 352–373.

Tulving E and Wiseman S (1975) Relation between recognition and recognition failure of recallable words. *Bull. Psychon. Soc.* 6: 79–82.

Tzeng OJL (1973) Positive recency in delayed free recall. *J. Verb. Learn. Verb. Behav.* 12: 436–439.

Underwood BJ (1945) The effect of successive interpolations and proactive inhibition. *Psychol. Monogr.* 59: v+33.

Verhaeghen P and Marcoen A (1993) Memory aging as a general phenomenon: episodic recall of older adults is a function of episodic recall of young adults. *Psychol. Aging* 8(3): 380–8.

Ward G, Woodward G, Stevens A, and Stinson C (2003) Using overt rehearsals to explain word frequency effects in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 186–210.

Waugh NC and Norman D (1965) Primary memory. *Psychol. Rev.* 72: 89–104.

Wickelgren WA (1967) Rehearsal grouping and hierarchical organization of serial position cues in short-term memory. *Q. J. Exp. Psychol.* 19: 97–102.

Wingfield A and Kahana MJ (2002) The dynamics of memory retrieval in older adults. *Can. J. Exp. Psychol.* 56: 187–199.

Woodward A and Murdock BB (1968) Positional and sequential probes in serial learning. *Can. J. Psychol.* 22: 131–138.

Yntema DB and Trask FP (1963) Recall as a search process. *J. Verb. Learn. Verb. Behav.* 2: 65–74.

Yonelinas AP (1999) The contribution of recollection and familiarity to recognition and source-memory judgments: a formal dual-process model and an analysis of receiver operating characteristics. *J. Exp. Psychol. Learn. Mem. Cogn.* 25(6): 1415–34.

Zaromb FM, Howard MW, Dolan ED, Sirotin YB, Tully M, Wingfield A, et al. (2006) Temporal associations and prior-list intrusions in free recall. *J. Exp. Psychol. Learn. Mem. Cogn.* 32(4): 792–804.

# 2.27 Episodic Memory: An Evolving Concept

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## 2.27.1 Introduction

Although the term episodic memory did not exist until about 35 years ago, it captures much of what philosophers, psychologists, and lay people have meant by memory or remembering. Episodic memory – or the recollection of events from one's personal past – is therefore one of the most fundamentally important concepts in the study of human memory. It is the capacity for episodic memory that enables one to recollect the multitude of details surrounding one's most cherished moments.

A challenge inherent in writing a review chapter on episodic memory is that it is not a static term; the essence of the term episodic memory has morphed and broadened considerably over the short time of the term's existence. It should be no surprise, then, that different empirical evidence has been brought to bear on the different meanings. A further twist is that a single person, Endel Tulving, both introduced the term (in 1972) and has modified its meaning many times in the years since. As a result, his theorizing and adaptation of the concept has spawned much of the relevant literature, and this chapter draws very heavily upon his work and emergent ideas.

We have chosen the following approach in organizing this chapter. We begin by attempting to identify a few of the historical landmarks or prominent features proposed in the conceptual development of episodic memory. We then choose two topics to consider in some depth. Specifically, we consider evidence supporting the proposition that episodic memory is a distinct memory system, different from other types of memory. We then consider research bearing on the suggestion that episodic memory may represent only one facet of a more general cognitive capacity that enables mental time travel into both the subjective past and future.

## 2.27.2 Historical Landmarks

### 2.27.2.1 A Taxonomic Distinction: Episodic and Semantic Memory

The concept of episodic memory was formally introduced in a seminal chapter by Tulving (1972), who drew a distinction between memory for specific events (episodic memory) and memory for general knowledge and facts (semantic memory). For example, remembering that the word elephant had been present in a list of previously studied words, recounting the events surrounding the day of one's college graduation, or reminiscing about the most recent Christmas dinner with a family member would be considered instances of episodic memory. Knowing that elephants live in Africa, the name of the college one attended, and that a family gathering typically implies a special occasion would be classified as examples of semantic memory (*See* Chapter 2.28).

In 1972, Tulving explained that laboratory studies of human memory had long been concerned with episodic memory. That is, most experiments were of the same general design: Present events for study and then measure how well they are remembered at a later time. At this time, episodic memory was associated with a certain type of task: Those that required recall or recognition of a prior episode.

Although episodic and semantic memory are both declarative (i.e., may be articulated) and can be differentiated from memory that cannot be expressed in terms of representational information (i.e., procedural memory, or memory of how to perform a skill, see Squire, 1987), there exists a fundamental and straightforward distinction between episodic and semantic memory: Episodic memory involves remembering an episode from one's past that is specific to time and place, whereas semantic memory involves general knowledge that is not associated with specific episodes.

Tulving summarized his seminal 1972 chapter as having made "a case for the possible heuristic usefulness of a taxonomic distinction between episodic and semantic memory and two parallel and partially overlapping information processing systems" (Tulving, 1972: p. 401). At the time, the episodic/semantic distinction was offered as a proposal that the two types of memory may be separable. As will be seen, the concept of episodic memory quickly grew to denote more than its originally intended meaning. The taxonomic distinction between episodic and semantic memory, however, is a central feature of the original conceptualization that has stood the test of time. Indeed, this distinction has been adopted by the field and is in widespread use.

Before proceeding further, it is worth considering the similarities and differences between the term episodic memory and a few other, related terms. Autobiographical memory refers to personal memories of one's own life. These can be of two types: episodic or semantic. Consider the following examples: Remembering the first day of grammar school would rely upon episodic memory, whereas knowing the name of one's grammar school relies upon semantic memory. Both examples, however, represent autobiographical (self-related) memory. We should acknowledge, though, that researchers define autobiographical memory in different ways, so not all would agree with this classification scheme. Explicit memory is another term related to episodic memory. Explicit memory is a term often used as a heuristic for the type of memory used on an explicit test of memory; an explicit test is one in which a person is asked to willfully attempt to retrieve the past. Explicit memory can be contrasted with implicit memory, which is the unintentional manifestation of memory (e.g., if you were to read this chapter a second time, it would likely be read faster).

### 2.27.2.2 Subjective Awareness

The role of subjective awareness in memory has long been a topic of interest for the field (e.g., feeling-of-knowing judgments, tip-of-the-tongue states; for a historical review see Metcalfe, 2000). In 1983, Tulving published *Elements of Episodic Memory*, in which he explicitly applied such ideas to his own work. In that volume, Tulving proposed that memories for personal episodes are characterized by a strong feeling of re-experiencing the past. In contrast, Tulving argued that retrieval of general knowledge from semantic memory lacked this phenomenological quality. That is, although someone may know a fact (e.g., that St. Louis is the site of a famous arch) and is aware that he or she acquired knowledge of this fact in the past, one does so in a way that does not necessitate re-experiencing the instance in which the fact had been learned.

Tulving further argued that the feeling of re-experiencing a previously encountered event is the *sine qua non* of episodic memory. He outlined a general framework (General Abstract Processing System, or GAPS; **Figure 1**) by which to understand the act of remembering from episodic memory (Tulving, 1983). The GAPS framework was intended to highlight many issues associated with retrieval from episodic memory. We focus here on how this framework predicts the emergence of subjective awareness (or recollective experience, as it was referred to in 1983). As can be seen in **Figure 1**, an encoded event is converted into a latent memory trace (or engram;

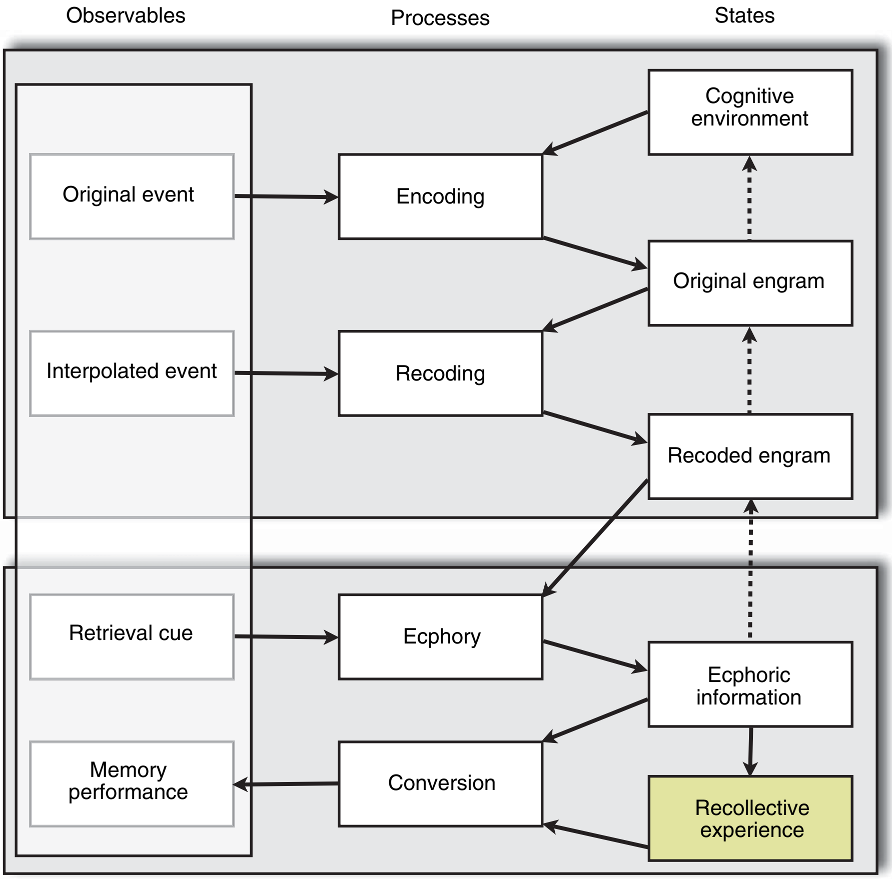


**Figure 1** General Abstract Processing System: A conceptual framework for understanding retrieval from episodic memory. Adapted from Tulving E (1983) *Elements of Episodic Memory.* New York: Oxford University Press.

Semon, 1904). However, it is unlikely that the event will be remembered exactly as it had originally occurred. For instance, the latent engram related to that event is subject to recoding (e.g., by virtue of related interpolated events). The recoded engram then interacts with a retrieval cue to produce ecphory: The evocation of information from a latent engram into an active state (Semon, 1904; Tulving and Madigan, 1970; Tulving, 1976; Schacter et al., 1978). That is, the synergistic product of the memory trace and the retrieval cue determine the nature of what is remembered (ecphoric information; *See* Chapter 2.16; Tulving, 1982), which in turn determines recollective experience. Accordingly, the rememberer will become aware of the encoded event to the extent that ecphoric information is representative of the original episode. At this time, no data were presented that directly assessed a participant's recollective experience for the contents of his or her memory.

On the basis of the notable absence of phenomenological data from the majority of verbal learning experiments (but see Metcalfe, 2000, who discusses various exceptions), Tulving (1983) suggested that students of psychology had not yet begun the study of episodic memory. Of course, this claim directly contradicts his previous (Tulving, 1972) assertion, which he declared in 1983 to have been "not very well thought out" (Tulving, 1983: p. 9). Prior research had assumed a correlation between a learner's behavioral response and subjective awareness. That is, if a learner was able to recall or recognize having previously encountered a given stimulus item (e.g., a word from a previously presented list) it was assumed that he or she mentally re-experienced the original event. It is now well-established that there is no direct correlation between behavior on a memory test and the cognitive processes underlying that behavior (Schacter, 1987; Tulving, 1989a; Jacoby, 1991; Roediger and McDermott, 1993; Toth, 2000; *See*

Chapter 2.33). Tulving (2002b) reflected on this issue by pointing out that episodic memory is concerned with what happened where and when. Typical verbal learning experiments assessed the what aspect but left when and where unqueried.

With this problem in mind, Tulving (1985b) devised a research paradigm designed to illustrate that a learner in a memory experiment does not necessarily remember the instance in which he or she experienced an event that he or she knows occurred in the past. This procedure was a starting point for exploring the nature of subjective awareness.

### 2.27.2.3 The Remember/Know Paradigm

The remember/know paradigm was introduced as a tool for investigating a learner's subjective awareness of a prior study episode (Tulving, 1985b), although current procedures have been modified somewhat from the original implementation (see Rajaram, 1993). For the most part, a remember/know experiment takes the form of the typical laboratory memory experiment. Learners study a set of stimulus materials at time one (e.g., a list of words) and take a memory test on those materials at time two. The innovation that Tulving introduced was to ask learners at the time of the memory test whether they actually remembered the exact prior occurrence of a given study item (e.g., the word ocean), or whether they just knew that the item had been presented, but could not remember the precise instance of its original presentation (Tulving, 1985b; Gardiner, 1988; Rajaram, 1993; Gardiner and Richardson-Klavehn, 2000; *See* Chapter 2.17).

Tulving (1985b) showed that learners could easily make these mental distinctions and that both remember and know responses were present during tasks that previously had been thought to tap episodic memory (i.e., recognition, cued recall, and even free recall). This important finding suggested that learners had two routes by which to recover the contents of a past study episode. Remembering was identified as the hallmark of episodic memory and was further associated with a unique mental state called autonoetic (self-knowing) awareness, implying a feeling of personally re-experiencing the past. Knowing was associated with semantic memory and noetic (knowing) awareness, a mental state lacking the feeling of personally re-experiencing the past. Further, memory tasks were found to vary in the degree to which they relied upon remembering, with free recall demonstrating the greatest level of remember responses (i.e., the greatest reliance on episodic memory). Hence, an important conclusion here is that no memory test is a pure measure of episodic memory, and tests designed to assess episodic memory differ in the degree to which they rely on the construct, with none achieving a pure assessment of episodic memory.

It is interesting to note that the subjective (autonoetic) awareness that Tulving had identified as a central component of episodic memory was similar to what pioneers of memory research had in mind when discussing remembering. For instance, William James (1890) wrote of remembering as, "a direct feeling; its object is suffused with a warmth and intimacy to which no object of mere conception ever attains" (James, 1890: p. 239). Hermann Ebbinghaus, (1885) adopted a generally understood conceptualization of memory that had been put forth by John Locke, defining remembering as the emergence of a sought after mental image that is "immediately recognized as something formerly experienced" (Ebbinghaus, 1885: p. 1). According to Locke, memory was the power of the mind "to revive perceptions, which it has once had, with this additional perception annexed to them, that it has had them before" (Locke, 1975: p. 150).

### 2.27.2.4 Retrieval Mode

Aside from the subjective awareness (or lack thereof) thought to accompany memory retrieval, Tulving (1983) outlined various other features by which he distinguished episodic from semantic memory (see also Tulving, 2005). At the time, the listing of differences was meant as a starting point for discussion, rather then any acknowledgment of hard-set facts. Importantly, the features on which episodic and semantic memory were hypothesized to differ were divided into three categories, each separately focusing on the information handled by episodic and semantic memory, their operations, and their applications. The main point of these subcategories was to emphasize that the distinction between episodic and semantic memory was more than just a difference in the type of information under consideration.

For instance, Tulving (1983) made a distinction regarding the manner in which access is gained to episodic and semantic knowledge. According to Tulving, access to information from episodic memory is deliberate and requires conscious effort. Conversely, semantic knowledge may be accessed in a relatively automatic fashion. For instance, stimuli in the environment are immediately interpreted on the basis of semantic knowledge. When reading a novel, the meanings of words come to mind with relative ease. However, it is only when one is in a particular state of mind that is focused on their personal past that the same stimulus may remind one of a particular episode. For example, single words have been shown to act as effective cues for the retrieval of personal autobiographical memories (Crovitz and Schiffman, 1974; Robinson, 1976); this is only the case, however, when participants are specifically instructed to use those words as retrieval cues. This state in which one focuses attention on their past and uses incoming information as cues for past experiences is referred to as retrieval mode (Tulving, 1983; Lepage et al., 2000). A potential exception to this rule involves spontaneous conscious recollection, wherein personal memories suddenly come to mind. One common example is the evocation of an emotional memory (e.g., one's first kiss) by a particular piece of music (see Berntsen, 1996, 1998). Similar examples have been offered in the prospective memory literature (McDaniel and Einstein, 2000; Einstein et al., 2005).

Tulving (1983) argued that retrieval mode constituted a necessary condition for retrieval from episodic memory but admitted, "we know next to nothing" about it (Tulving, 1983: p. 169). In terms of the behavioral literature on the topic, the same statement holds true today. Although subsequent research on the topic has illuminated the nature in which the presence/absence of retrieval mode may be manipulated in the context of a memory experiment (e.g., retrieval intentionality criterion, Schacter et al., 1989), we have not learned much more about the state itself.

Recent advances in neuroimaging techniques (see section titled "Functional neuroimaging") have revived interest in the study of retrieval mode. For example, Lepage et al. (2000) suggested that brain regions showing similar patterns of brain activity during either successful or failed attempts of episodic retrieval (relative to a control task that does not engage episodic retrieval processes) can be taken as neuroanatomical correlates of retrieval mode. Reviewing the relevant literature, Lepage et al. identified six frontal lobe regions (mostly right lateralized) that appear to become active whenever participants attempt to retrieve past information, regardless of whether they are successful or not. Thus, the underlying nature of retrieval mode has not yet been delineated, but neuroimaging techniques may prove useful in approaching this issue.

### 2.27.2.5 Subjective Awareness, Self, and Time

As we have mentioned, the concept of episodic memory has been considerably refined over the years. According to Tulving's most recent conceptualization, episodic memory is a recently evolved, late-developing, and early-deteriorating past-oriented memory system, more vulnerable than other memory systems to neuronal dysfunction, and probably unique to humans. It makes possible mental time travel through subjective time, from the present to the past, thus allowing one to re-experience, through autonoetic awareness, one's own previous experiences (Tulving, 2002b: p. 5).

Thus far we have highlighted subjective (autonoetic) awareness as the defining feature of retrieval from episodic memory. Equally important are concepts of self and subjective time (Tulving, 2002a,b). That is, episodic memory requires the capacity to represent a psychologically coherent self that persists through subjective time, whose past experiences are recognized as belonging to the present self (self-contiguity; Klein, 2001). Klein (2001; see also Klein et al., 2004) argues that a breakdown of self-contiguity disrupts the ability to represent past and present mental states as being aspects of the same personal identity, thus leaving an individual incapable of identifying a current mental state as one that was previously experienced. Klein (2001) reviews compelling evidence to support this claim. For example, individuals with schizophrenia – a population characterized by impairments in self-contiguity – have profound deficits in episodic memory (McKenna et al., 1994).

### 2.27.2.6 The Episodic Memory System

As can be seen by the 2002 definition (quoted in the previous section), episodic memory grew to encompass much more than the type of memory that allowed one to recall or recognize prior events. It became a hypothetical neurocognitive memory system that is characterized, relative to other memory systems, by its unique function and properties (Tulving, 1984, 1985a; Sherry and Schacter, 1987; Schacter and Tulving, 1994). Of course, this basic idea was foreshadowed somewhat by the earlier description (even in the 1972 description regarding partially overlapping processing systems), but the earlier emphasis had been on the basic taxonomic distinction and not on the much more bold claim that it is a memory system.

What exactly is a memory system, and what might the criteria be for establishing one? These questions have spurred a great deal of controversy, much of which appeared in the context of the emerging literature on implicit memory in the late 1980s and early 1990s (Tulving, 1985a; Sherry and Schacter, 1987; Roediger et al., 1990, 1999; Schacter and Tulving, 1994; Buckner, 2007). Some theorists were concerned that the lack of stringent criteria would lead to a proliferation of putative memory systems, many of which were probably not well justified. We wish to sidestep that general debate here; our view is that although the criteria for establishing a memory system are not well-specified (and are often not met even when specified), there is nonetheless strong evidence that episodic memory represents a fundamentally different kind of memory than semantic memory and that the hypothesis that it is indeed a distinct memory system is certainly viable. Here we choose to focus on what was meant by this claim that episodic memory should be considered a memory system and review some of the evidence bearing on the claim.

First, the episodic memory system enables its owner to process (i.e., encode, store, and retrieve) personally experienced episodes. In this way, it allows one to accomplish a feat not possible without the system. Secondly, episodic memory can be differentiated from semantic memory on a variety of dimensions (Tulving, 1972, 1983). We have already addressed one of these dimensions at length, namely the conscious awareness that characterizes episodic (autonoetic awareness) relative to semantic (noetic awareness) memory. Hence, episodic memory has a set of properties that differentiate it from other systems.

It is important to note that the episodic memory system is hypothesized to be related to and have evolved from phylogenetically earlier systems, including semantic memory (Tulving, 1985b, 1995). That is, the ability to consciously re-experience a specific event from the past may have grown out of a more general ability to use the past in an informative fashion, albeit one lacking a sense of subjectively reliving the event (see **Figure 2**). The episodic memory system "depends upon but goes beyond the capabilities of the semantic system. It could not operate in the absence of the semantic system" (Tulving, 1989b: p. 362). Of course, the evolutionary relation between episodic memory and semantic memory is not subject to laboratory investigation. As will be seen, a similar relation appears to exist in the course of ontogenetic development, though, whereby episodic memory emerges in the presence of fully functioning semantic memory.

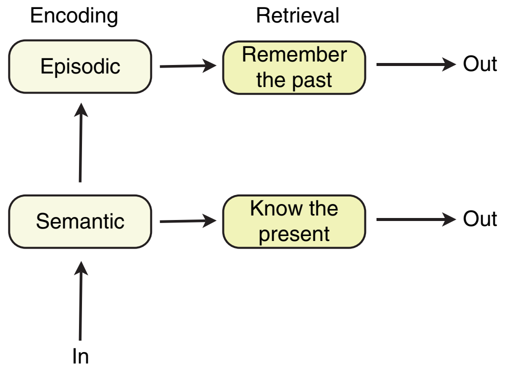


**Figure 2** Sketch of the relations between semantic and episodic memory. Information can be encoded into semantic memory independent of episodic memory but must be encoded into episodic memory through semantic memory. Encoded and stored information is potentially available for retrieval from one of the two systems or from both of them. Adapted from Tulving and Markowitsch (1998).

In the following section, we present evidence from neuropsychology, functional brain imaging, and developmental psychology consistent with the idea that episodic memory may in fact represent a viable neurocognitive system or is at least functionally dissociable from semantic memory.

## 2.27.3 Converging Evidence for the Episodic Memory System

The idea that episodic memory might represent a distinct memory system emerged largely out of the behavioral psychological literature, where it was shown that a particular independent variable might affect performance on one measure or set of measures (e.g., measures thought to draw largely upon episodic memory) but not affect performance (or affect performance in the opposite direction) on different measures, thought to draw largely on semantic memory. For example, level of processing during encoding affects the likelihood of later remembering but not knowing (when the remember/know paradigm is used; see Yonelinas, 2002, for review). Perhaps the most compelling evidence for the idea comes from brain-based studies, particularly neuropsychological studies. Here it can be shown that some patients lose the ability to use episodic memory while retaining other classes of memory, including semantic memory. Following, we review some of this evidence.

### 2.27.3.1 Neuropsychology

Neuropsychological observations of brain-damaged individuals have contributed a great deal to our understanding of the organization of human memory in the brain. Perhaps the most famous contribution is that of Scoville and Milner (1957), who reported the case of patient HM. HM incurred dense amnesia following a bilateral resection of the medial temporal lobes. Since then, a great deal of converging evidence from neuropsychological observations of human patients, neurological experimentation using animal subjects, and more recent advances in functional brain imaging techniques has corroborated Scoville and Milner's original observation: The medial temporal lobes play an important role for memory (for an early reference, see Bekhterev, 1900).

Of particular interest, Scoville and Milner (1957) classified the impairment observed in patient HM as one of declarative memory. That is, no distinction was made between episodic and semantic memory. Of course, this is not surprising given that the distinction was not introduced to the neuropsychological community for another 30 years (Tulving, 1985b; although see Nielsen, 1958, for a foreshadowing of the distinction). Another potential reason the distinction was not made is because it was not readily apparent. HM's surgical resection encompassed large portions of the medial temporal lobes, including, but not limited to, the hippocampal formation. It has recently been considered that hippocampal damage is particularly associated with deficits of episodic memory, whereas semantic memory problems arise as a result of adjacent cortical damage (Mishkin et al., 1997; Aggleton and Brown, 1999). Accordingly, both episodic and semantic memory may have been damaged in patient HM.

Vargha-Khadem and her colleagues have recently reported on a set of three amnesic patients, each of whom sustained bilateral pathology restricted to the hippocampus following an anoxic episode in early life (ranging from birth to 9 years; Vargha-Khadem et al., 1997). Unlike most amnesic patients, their ability to acquire knowledge remains intact. As a result, all three patients have been able to progress through the educational system with little trouble. However, all three are severely impaired in their ability to recall events, even those that occurred minutes previously. These cases represent a clear dissociation between episodic and semantic memory function in the presence of brain damage restricted to the hippocampus.

Although dissociations between episodic and semantic memory are rarely clear-cut, there do exist many case reports in which one is relatively more impaired than the other. Most such cases have reported greater deficits of episodic memory relative to semantic memory (e.g., Cermak and O'Connor, 1983; Calabrese et al., 1996; Kitchener et al., 1998; Levine et al., 1998; Viskontas et al., 2000), although the reverse pattern also occurs (e.g., Grossi et al., 1988; De Renzi et al., 1997; Yasuda et al., 1997; Markowitsch et al., 1999). The reversed pattern (i.e., greater impairment of semantic than episodic memory) is not well accommodated by the idea that episodic memory requires semantic memory to operate.

It is important to note that these case studies are characterized by various etiological factors and resulting patterns of brain impairment that are not restricted to the medial temporal lobes. In general, there is good reason to believe that the operations of various memory systems (including episodic and semantic) depend upon highly distributed and interacting regions of the brain (Mesulam, 1990; Nyberg et al., 2000). For instance, although the role of hippocampus is well established, deficits of episodic memory are also highly correlated with frontal lobe pathology (e.g., Ackerley and Benton, 1947; Freeman and Watts, 1950; Stuss and Benson, 1986; Wheeler et al., 1997).

As an example of relative impairment of episodic memory, consider patient ML (Levine et al., 1998). Following a severe closed-head injury, patient ML became amnesic for pretraumatic events. Although ML retained the capacity to recount many autobiographical facts, he was unable to re-experience any specific event associated with them. For instance, ML could recount the name of a high school teacher perfectly well but was unable to recollect any experience associated with that individual. In brief, the episodic component of patient ML's autobiographical memory was missing. His pathology was restricted to right ventral frontal lobe, including the unicinate fasciculus, a band of fibers connecting frontal and temporal cortices. Patient ML is one of many brain-damaged patients who have lost much of their episodic and semantic memory, with no accompanying anterograde (posttrauma) amnesia.

That is, these patients are able to learn new information. With respect to these patients' retrograde (pretrauma) memory problems, semantic memory typically recovers, while episodic memory remains largely impaired.

As an example of disproportionate impairment of semantic memory, consider the report by Grossi et al. (1988) of a student who lost her ability to reproduce factual knowledge that she had learned prior to her injury. For instance, she was unable to recount various facts learned in school, although she could remember specific meetings with instructors. Summarizing over many such observations, Kapur (1999) concluded that, "loss of factual, semantic memories is readily dissociable from loss of memory for personally experienced events" (p. 819).

Perhaps the most well-documented example of a dissociation between episodic and semantic memory is a patient known as KC, who has been investigated by Tulving (1985b) and his colleagues at the University of Toronto. At the age of 30, patient KC sustained damage to several regions of his brain (including the medial temporal lobes) following a closed-head injury from a motorcycle accident (Rosenbaum et al., 2000, 2005). As with many amnesic patients, neuropsychological testing revealed that KC had retained many of his cognitive capacities. For instance, his intelligence and language faculties remain largely unaffected; he can read and write; he is able to focus and pay close attention to a conversation; he is capable of performing a wide variety of mental tasks, including visual imagery; and his short-term memory is normal.

KC also knows many details about his personal past. Among other things, he knows the names of many of the schools that he attended, the address of his childhood home, the make and color of his former car, and the location of his family's summer home. That is, KC's semantic knowledge of information acquired prior to the brain trauma remains largely intact. Nonetheless, KC cannot remember a single personal episode associated with this knowledge. For instance, although he can readily describe the process of changing a flat tire, he cannot remember ever having performed this task. In fact, KC cannot remember a single episode from his lifetime. This lack of episodic memory extends to highly emotional events; KC has no recollection regarding the untimely death of his brother or a bar fight that left him with a broken arm.

Given the diffuse nature of KC's brain pathology, it remains unclear what the precise cause of the clear dissociation between episodic and semantic memory might be, although strong arguments can be made regarding damage to regions of KC's medial temporal lobes (e.g., Vargha-Khadem et al., 1997; Klein et al., 2002) and frontal cortex (see Wheeler et al., 1997). Regardless, the story of patient KC is a remarkable one and suggests that there may emerge a biological dissociation between episodic and semantic memory.

As a whole, these studies show that various forms of deficits can be found with respect to episodic and semantic memory. Note, however, that there has not yet been successful resolution of how the current concept of episodic memory could accommodate finding a properly functioning episodic memory system occurring in a person with semantic memory deficits. Nonetheless, the more general finding that episodic and semantic memory can be dissociated not just as a function of independent variables but also in neuropsychological patients is consistent with the idea that episodic memory should be considered a memory system.

### 2.27.3.2 Functional Neuroimaging

There now exist seemingly countless neuroimaging studies of episodic memory. Here we identify a few general patterns that indicate a brain-based dissociation between episodic and semantic memory. We have found it necessary to be brief, and we suggest that the interested reader seek some of the in-depth reviews that detail the wealth of studies that have shaped our understanding of episodic memory and how it is represented in the brain.

Traditional psychological studies and (especially) lesion studies do not allow the easy separation of retrieval from storage. In neuroimaging studies, however, retrieval effects can arguably be better isolated. Here we focus primarily on retrieval from episodic memory for a couple reasons. First, the encoding of information into episodic memory seems to rely largely upon retrieval of information from semantic memory (Tulving et al., 1994; see also Prince et al., 2007). Storage is a phase not well studied with the methods under consideration here. Finally, retrieval has been argued to be the foundation for understanding memory; indeed, Roediger (2000) entitled a chapter "Why retrieval is the key process in understanding human memory."

Functional neuroimaging techniques, such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI), allow neuroscientists to examine the healthy human brain at work.

When participants engage in a given cognitive task, PET or fMRI provide information about the level of cerebral blood flow (PET) or blood oxygenation level (fMRI) localized in the brain regions recruited for the task. Such metabolic changes correlate highly with underlying neuronal activity and thus provide important insights into the brain structures that might underlie specific cognitive tasks.

One challenge in conducting brain-imaging research lies in experimental design. In the typical design, metabolic changes associated with two cognitive tasks are contrasted with one another in hopes of isolating the neural correlates of the cognitive process of interest. Researchers attempt to contrast a pair (or in some cases a set) of tasks that are highly similar to one another but that vary on one key dimension. Note that such a contrast highlights differences between tasks but (in the absence of a third, low-level baseline task) is unable to address areas of common activation.

For instance, in order to identify the neural correlates associated with retrieval from episodic memory, studies have contrasted a task that draws upon episodic memory with a second retrieval task that does not involve the reinstatement of specific spatial-temporal details (e.g., retrieval of general knowledge, which draws upon semantic memory). Although one may be certain that one task reasonably depends more on episodic memory and the other more on semantic memory, neither task is a direct window into the type of memory it is designed to reflect; confidence is gained, however, when results replicate across studies and tasks. This approach makes testable the assumption made by Tulving that retrieval from episodic memory relies upon semantic memory but adds to it certain other processes or brain regions. It is therefore possible to see whether episodic memory seems to rely upon the same brain regions as semantic memory with the addition of others.

With the neuropsychological studies just reviewed in mind, one could make some predictions with respect to how episodic and semantic memory might differ. Relative to some lower-level baseline task, semantic and episodic memory would be expected to reveal very similar activity. To the extent that episodic memory indeed builds upon semantic memory, any differences seen would be expected to be in the direction of greater activity for episodic than semantic memory. Specifically, retrieval from episodic memory would be expected to rely more upon hippocampus (and potentially surrounding structures) than would semantic memory.

In general, neuroimaging studies of episodic memory do not line up perfectly with the neuropsychological studies, and the precise reasons behind this situation are still unclear (Buckner and Tulving, 1995). One way in which the data are consistent with the theory is that in general, activation for retrieval from semantic and episodic memory tasks is very similar, with many (but certainly not all) differences tending to go in the direction of episodic retrieval. One puzzling finding is that the hippocampus is not reliably seen as particularly active during retrieval from episodic memory, especially as typically studied, with verbal materials (Fletcher et al., 1997; Schacter and Wagner, 1999). However, neuroimaging studies of episodic memory using autobiographical memories as the content of retrieval, rather than word lists learned in the laboratory, do overlap nicely with lesion studies (e.g., hippocampal activity is commonly reported in neuroimaging studies of autobiographical memory retrieval). Thus, questions regarding the differences obtained using differing methodologies may ultimately need to focus on the tasks being used in conjunction with the method of inquiry.

Direct comparisons of tasks designed to rely on episodic and semantic memory have not been reported as often as one might think (but for some examples see Shallice et al., 1994; Fletcher et al., 1995; Nyberg et al., 1996; McDermott et al., 1999a,b). Those who have done so show that regions within frontal cortex are more active for episodic than semantic memory. In the early 1990s (when the literature was based largely on PET methodology), retrieval-related activation in frontal cortex was almost always right-lateralized in or near Brodmann Area (BA) 10 (for a review see Buckner, 1996); more recent studies using fMRI tend to show bilateral or left-lateralized activity here. Following this relatively unanticipated finding, much work has been devoted to attempting to identify the processing underlying these prefrontal regions involved in episodic retrieval. Some hypotheses regarding the processes include retrieval mode (the mental set of attempting to retrieve the past, LePage et al., 2000), retrieval success (McDermott et al., 2000), postretrieval processing (a set of processes following the initial recovery of information in the retrieval phase; see Rugg and Wilding, 2000), or the amount of retrieval effort extended (Schacter et al., 1996). Different regions certainly contribute to different processes, but it is not yet clear which regions are contributing which processes (or even if the correct processes have been identified). A precise understanding of the situation awaits further work.

Another somewhat surprising finding is the role parietal cortex appears to play in episodic memory. Contrasts of episodic memory tasks with semantic memory tasks tend to activate regions within bilateral inferior parietal cortex (within BA 40) and within medial parietal cortex (precuneus and posterior cingulate/retrosplenial cortex, e.g., McDermott et al., 1999b), and contrasts of episodic retrieval with other comparison tasks have elicited similar findings, which have led to recent attempts to identify the role of parietal cortex in memory (Shannon and Buckner, 2004; Wagner et al., 2005). Although the possible importance of parietal cortex in episodic retrieval was at the time unanticipated from the lesion literature, a closer look at the lesion literature shows that lesions on medial parietal structures can indeed produce what has been called retrosplenial amnesia (Valenstein et al., 1987).

Of historical importance is an early generalization in functional imaging studies of human memory, which suggested an apparent asymmetry between episodic encoding and retrieval processes: Hemispheric Encoding/Retrieval Asymmetry (HERA; Tulving et al., 1994). In general, episodic encoding was thought to be more strongly associated with left frontal lobe activity (than right), whereas episodic retrieval was more strongly associated with right frontal lobe activity (than left). Because episodic encoding is believed to involve a high degree of semantic elaboration of incoming information, semantic retrieval has also been associated with left frontal lobe activity. As reviewed above, most researchers would probably argue that the more profitable approach is to attempt the ascription of processes to specific cortical regions (rather than making broad generalizations to larger regions of cortex, e.g., the role of the right frontal lobe). Nonetheless, the HERA idea was influential in the late 1990s and served as a guiding framework for a number of studies.

In this short review, we have necessarily omitted many relevant issues from consideration. Among those are fMRI studies of remembering and knowing (e.g., Henson et al., 1999; Eldridge et al., 2000; Wheeler and Buckner, 2004) and studies from the tradition of autobiographical memory (see Maguire, 2001 for review). Further, event-related potential (ERP) studies anticipated the importance of parietal cortex in retrieval (Rugg and Allan, 2000) and some of the differences seen in remembering and knowing.

To summarize, initial contrasts of episodic and semantic memory were expected to elucidate the role of the hippocampus in episodic memory. Although some studies showed such activation, many did not. Attention then turned to the role of frontal cortex in remembering (with an accompanying new look at the neuropsychological literature). Most recently, the role of parietal cortex has become of great interest. The questions being asked are essentially of the flavor of which regions contribute which processes. In our view, this approach is the best one to take at this point (see, too, Roediger et al., 1999). Neuroimaging studies have not well adjudicated the question of whether episodic memory is a memory system but have clarified thinking with respect to how (in process terms) episodic and semantic memory differ and what the neural substrates of those different processes might be. Note that this review has focused on studies that are somewhat relevant to the question of whether episodic memory can be thought of as a memory system dissociable from semantic memory; other related issues (e.g., a comparison between remembering and knowing or between successful and unsuccessful retrieval attempts) have not been addressed, as we see them as less critical to the question under consideration here (although they address fundamentally important issues in the topic of remembering).

### 2.27.3.3 Development of Episodic Memory: The Magic Number 4 ± 1

Episodic memory is a late-developing memory system that emerges in the context of an already existing ability to draw upon the past in an informative fashion. Beginning at an early age, children are able to acquire vast amounts of knowledge from their surroundings. For instance, within the first few years of life, a child will have learned and retained the meanings of thousands of words and detailed knowledge pertaining to the identities of various objects in their environment. This early accumulation and utilization of knowledge is best characterized in terms of semantic memory. That is, although children know about many things that they have learned in the past, the capacity to reliably remember specific events does not emerge until approximately 4 years of age.

As with various other developmental milestones, episodic memory emerges in a gradual manner. Specifically, although most 3 year olds have great difficulty with tasks that are believed to require episodic memory, there do appear glimpses that this capacity is beginning to manifest itself. For instance, by the age of

3 years, many children are capable of reporting the content of an event that they had previously witnessed in the laboratory (Howe and Courage, 1993; Bauer et al., 1995; Bauer and Werenka, 1995). However, the descriptions are typically vague, and it is difficult to know whether these children remember the precise episodes they describe, or whether they just know about them.

Johnson and Wellman (1980) have presented data suggesting that the ability to discriminate between the mental states of remembering and knowing does not emerge until the age of 5 years. In their study, few 4 year olds, some 5 year olds, and most first-grade children demonstrated an understanding of the distinction. This finding is consistent with the claim that children under the age of 4 years are likely relying upon semantic memory when reporting on events from their past.

A great deal has been learned about the emergence of episodic memory through the use of source memory tests (Johnson and Raye, 1981; Johnson et al., 1993). Not only do such tests require the participant to remember the content of a prior study episode, but the participant must also remember the context (e.g., when, where, etc.) in which that content was learned. Source memory tasks are believed to be good tests of episodic memory in that a correct response requires the reinstatement of specific spatial–temporal aspects of the originally encoded event. Studies that have adapted the source memory paradigm for use with children are consistent in their findings: The capacity for episodic memory appears to emerge around the age of 4 years.

In a particularly clear demonstration, Gopnik and Graf (1988) had 3-, 4-, and 5-year-old children learn the contents of a drawer under one of three conditions. The children were told about the contents of the drawer, were allowed to see the contents of the drawer for themselves, or were given hints so they could infer the contents of the drawer. During a later test, the researchers were interested in the children's ability to answer two questions: What was in the drawer, and how do you know? With regard to the first question, retention of the contents of the drawer was comparable across all age groups. All children knew what they had seen. This was not the case when the children were required to discriminate the source of their knowledge. Although the 5-year-old children made few mistakes in describing the manner in which they had learned about the contents of the drawer, the 3 year olds performed at chance levels (see also Wimmer et al., 1988; O'Neill and Gopnik, 1991). That is, only the 5-year-old children remembered the circumstances under which they had seen the contents.

This basic finding has been replicated many times (e.g., Lindsay et al., 1991; Taylor et al., 1994; see Wheeler, 2000b; Drummery and Newcombe, 2002, for a review). In general, 3 year olds show initial signs of a developing episodic memory system, but for the most part they have great difficulty when they are required to report specific details of past occurrences. By the age of 5 years, most children appear to possess fully functioning episodic memory, although this capacity is likely to continue to develop thereafter (for related discussion, see Nelson, 1984; Gopnik and Slaughter, 1991; Flavell, 1993; Howe et al., 1994; Perner and Ruffman, 1995; Wheeler et al., 1997; Wheeler, 2000a,b; Tulving, 2005; Piolino et al., 2007). With respect to the purposes of our present discussion, children of all ages (except those younger than 8 months; Wheeler, 2000b) possess intact semantic memory, the context in which episodic memory develops.

## 2.27.4 Episodic Memory and Mental Time Travel

Finally, we consider the most recent conceptual development regarding episodic memory, namely, its relation to mental time travel. The idea, initially delineated by Tulving (1985a), is roughly that humans (and perhaps only humans) possess the ability to mentally represent their personal past and future (see also Suddendorf and Corballis, 1997; Tulving, 2002a). That is, just as we can vividly recollect our personal past, we can also, with a seemingly equal level of vividness and efficacy, mentally represent personal future scenarios (episodic future thought).

Beginning with the pioneering work of Hermann Ebbinghaus (see also Nipher, 1876), students of psychology and neuroscience have expended more than 100 years of thought and careful experimentation toward an understanding of human memory. However, there has been surprisingly little inquiry into episodic future thought. According to Tulving and his colleagues, both capacities represent an important component of autonoetic consciousness, which is the ability to "both mentally represent and become aware of subjective experiences in the past, present, and future" (Wheeler et al., 1997: p. 331).

Next, we review evidence suggesting that the capacity for episodic future thought (Atance and

O'Neill, 2001) is intricately related to the ability to vividly recollect one's past. Specifically, it has been argued that impairments to both capacities co-occur following brain damage (Tulving, 1985; Klein et al., 2002), that both share similar neural networks (Okuda et al., 2003; Addis et al., 2007; Szpunar et al., 2007), and that both appear rather late in ontogenetic development (Busby and Suddendorf, 2005).

### 2.27.4.1 Neuropsychology

For an example of selective damage, consider again patient KC. Along with a selective deficit of episodic memory, KC is unable to project himself mentally into the future. When asked to do either, he states that his mind is "blank"; when asked to compare the kinds of blankness in the two situations, he says it is the "same kind of blankness" (Tulving, 1985: p. 4).

A similar profile is exhibited by patient DB, studied by Klein and colleagues (Klein et al., 2002); DB experienced an anoxic episode following cardiac arrest and can no longer recollect his past, nor can he project himself into the future. Interestingly, Klein et al. revealed that DB was able to think about the past and future in a nonpersonal (semantic) manner. That is, while DB could not report any of what he had personally experienced in the past or any of what he might experience in the future, he could report general facts related to the past, along with what might generally occur in the future (e.g., concerns about global warming).

Hassabis et al. (2007) replicated and extended these findings in a more systematic fashion. In that study, the authors presented a set of five amnesic patients with brain damage localized to the hippocampal formation. Each of these patients is densely amnesic for personal episodes but retains intact semantic memory. To test whether the profound deficit of episodic memory was accompanied by a deficit in episodic future thought, the authors tested the patients' ability to form mental images of novel future experiences. Specifically, the patients were presented with a series of 10 cues and asked to imagine themselves in the context of either novel (e.g., castle) or familiar (e.g., possible event over next weekend) settings. Relative to those of control subjects, the patients' images were "fragmentary and lacking in coherence" (Hassabis et al., 2007: p. 1728).

The aforementioned case studies represent only a few of many reports about amnesic patients. Most other investigations into the phenomenon of amnesia have, for the most part, focused on the memory problems inherent in such patients. For instance, many others have been interested in investigating the relative effects of brain damage on episodic versus semantic memory (Kapur, 1999; Wheeler and McMillan, 2001). Thus, it remains uncertain whether comparable impairments in backward- and forward-going aspects of mental time travel are common in all such patients.

Nevertheless, there do exist prior reports describing amnesic patients as living in the permanent present (Barbizet, 1970; see also Lidz, 1942), and cases similar to the ones mentioned above have been reported (Stuss, 1991; Dalla Barba et al., 1997; Levine et al., 1998). In addition, there exist extensive reviews of case study reports on patients with frontal lobe damage (e.g., Luria and Homskya, 1964; Luria, 1969). One common characterization of these patients is that they seem to be detached from the past and unconcerned about matters related to their personal future (Ackerley and Benton, 1947; see also Freeman and Watts, 1950; Ingvar, 1985; Fuster, 1989; Wheeler et al., 1997; Wheeler, 2000a).

### 2.27.4.2 Functional Neuroimaging

The psychological study of episodic future thought has been attempted only sporadically (D'Argembeau and Van der Linden, 2004, 2006; Szpunar and McDermott, in press), and the search for its neural substrates has begun only very recently. Note that we draw an important distinction between episodic future thought and more general thoughts of the future, such as planning, which has received extensive attention in the literature and is thought to rely heavily on regions within frontal cortex (Stuss and Benson, 1986; Shallice, 1988; Fuster, 1989). The set of procedures under examination here – comprising episodic future thought – are arguably a necessary precursor to planning; without the ability to envision oneself spending a weekend with friends on the ski slopes, for example, it is unlikely that one would plan the weekend.

Consider a recent PET study by Okuda et al. (2003). Participants were asked to speak aloud for 1 min about their near future (the next few days), far future (next few years), near past (recent few days), and far past (last few years). Activity during these states was compared to each other and to a fifth, baseline state, which involved talking about the meaning of various words. Two regions in anteromedial frontal cortex and medial temporal cortex were more active for the future conditions than the past conditions; other regions (in nearby medial frontal and medial temporal cortex) exhibited the opposite effects (more activity for past conditions relative to future). The authors suggested that remembering the past and planning for the future likely share common neural correlates and that it may be necessary for past experiences to be reactivated in order to facilitate an effective plan for future events (see too Burgess et al., 2000). Their data suggest that specific regions within frontal and medial temporal cortex might be suited for these functions. Although quite interesting, these data are of questionable relevance to the topic under consideration because in speaking about the future, the participants in this study tended not to focus upon specific future episodes but instead spoke about intentions, conjectures, and schedules. In contrast, these aspects were not much present when speaking about the past (i.e., the past tended to focus on specific episodes). In the other two studies to be considered, participants were asked to focus on specific episodes (either episodes that might take place in the future or ones that indeed took place in the past).

Szpunar et al. (2007) used fMRI to identify brain regions that might be important for representing oneself in time and then to examine those regions to see whether or not they are similarly engaged by past and future thought. In order to accomplish this goal, participants were asked to perform a set of three tasks. In all of these tasks, participants viewed a series of event cues (e.g., birthday party) and were asked to envision a specific scenario in response to the cues. In one task, the instructions were to recollect a personal memory of that kind of event (e.g., a specific previous birthday party). The second task instructed subjects to use the cue to think of a specific future scenario involving the cue. Activity common to both tasks (i.e., a conjunction of the past and future tasks) was contrasted with a third task that involved many of the processes common to past and future thought (e.g., mental construction of lifelike scenarios) but that lacked a sense of representing oneself in time. Specifically, the control task required participants to use the cue as a starting point for imagining former U.S. President Bill Clinton in a specific scenario. Bill Clinton was chosen because pretesting showed that he is easy to visualize in a variety of situations.

As can be seen in **Figure 3**, several regions in the brain's posterior cortex were similarly engaged during personal past and future thought, but not during the control task. These regions were located in the occipital cortex, the posterior cingulate cortex, and the medial temporal lobes. Previous research had shown that these regions are consistently engaged during tasks such as autobiographical memory (Svoboda et al., 2006) and mental navigation of familiar routes (Ghaem et al., 1997; Mellet et al., 2000;

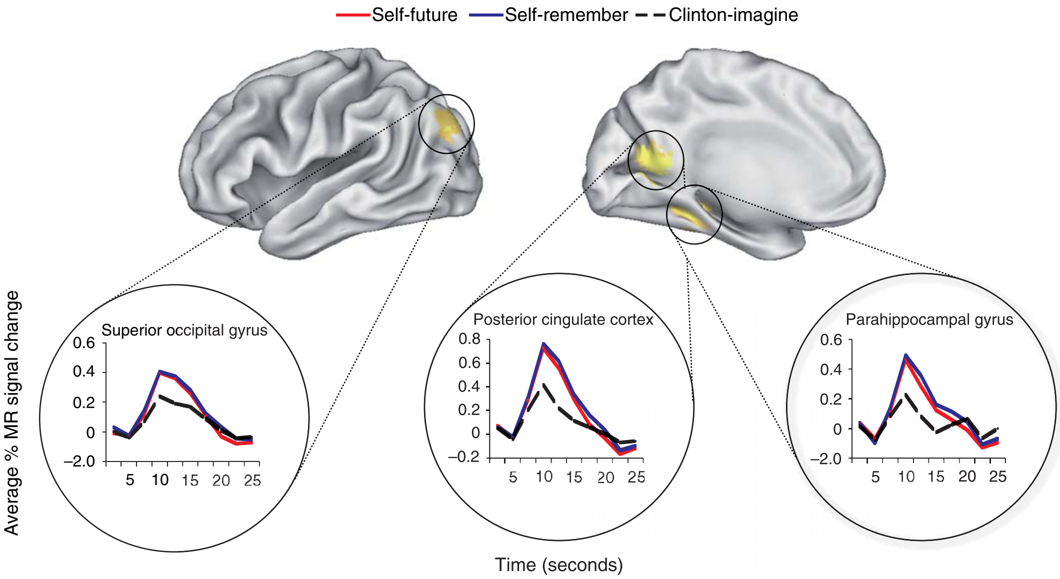


**Figure 3** Percent signal change for brain regions exhibiting indistinguishable patterns of activity across time while participants envisioned their personal future and recollected the past. Imagining a familiar individual in similar scenarios resulted in a pattern of activity different from both the past and future tasks. Regions appear within superior occipital gyrus, posterior cingulate cortex, and parahippocampal gyrus. Data from Szpunar, Watson, and McDermott (2007).

Rosenbaum et al., 2004), which encourage participants to recount previously experienced settings (Aminoff et al., 2007). Szpunar et al. hypothesized that asking participants to envision a personal future scenario likely required similar processes. That is, in order to effectively generate a plausible image of the future, participants reactivate contextual associations from posterior cortical regions (cf., Bar and Aminoff, 2003; Okuda et al., 2003; Bar, 2004). Postexperiment questionnaires indicated that participants did tend to imagine future scenarios in the context of familiar settings and people.

A similar pattern of fMRI data has been presented by Addis et al. (2007), who parsed episodic future thought and remembering into two separate phases: construction and elaboration. That is, subjects were given cues (e.g., car) and asked to envision themselves in the future or to remember a past event. Once the event was in mind, they were to press a button and to then keep thinking about the event for the remaining time of the 20 s. They then rated the level of detail, the emotional intensity, and the perspective (first person or third person) before moving to the next trial. Of most interest to the present discussion is the construction phase (in part because the activity during the elaboration phase could not be separated from the activity during the three subsequent rating phases). Relative to baseline tasks that involved sentence generation and imagery, constructing the past and future episodes led to equivalent activity in a set of posterior cortical regions similar to those reported by Szpunar et al. (2007).

In light of such findings, Schacter and Addis (2007a) have proposed what they call the constructive episodic simulation hypothesis. They argue that one important function of retaining personal memories is the ability to sample their contents in mentally constructing (predicting) novel future scenarios (see also Szpunar and McDermott, in press). That past and future thought are so closely related provides insight into why certain populations who lack access to specific personal details of their past (e.g., brain damaged amnesic patients) are also unable to imagine specific personal future scenarios.

Finally, it should be noted that although this is a very recently emerging topic of interest, we anticipate that the above-mentioned studies will act as a catalyst for future research. Several early concept papers and reviews on the topic have also been put forth (Buckner and Carroll, 2007; Miller, 2007; Schacter and Addis, 2007a; Szpunar and McDermott, 2007). There is a recent but clear trend in thinking about episodic memory to include episodic future thought.

### 2.27.4.3 Development of Episodic Future Thought

A small but growing line of research suggests that the ability to project oneself into the future emerges in concert with the ability to vividly recollect the past. For instance, Busby and Suddendorf (2005) have shown that it is not until about the age of 5 years that children are able to accurately report what they will or will not do in the future (i.e., tomorrow), as well as what they have or have not done in the past (i.e., yesterday). Many of these studies have focused on requiring children to predict future states (e.g., Suddendorf and Busby, 2005) and have revealed both that the emergence of this capacity is not based simply on semantic knowledge related to the future event (Atance and Meltzoff, 2005) and that it is not dependent on language (Atance and O'Neill, 2005).

## 2.27.5 Is Episodic Memory Uniquely Human?

Perhaps the most intensely debated topic regarding episodic memory is whether this capacity, and mental time travel more generally, is uniquely human. There is no dispute that nonhuman animals possess memory. For example, consider a dog that buries a bone in the backyard and retrieves it the following day. How does the dog accomplish this task? Perhaps the animal mentally travels back in time, as we might. Alternatively, the animal may simply know that the backyard is somewhere where things are buried and may be able to make use of salient cues to locate the object it desires. Or the animal may know exactly where the bone is without remembering the episode in which it was placed there. We suspect most dog owners would suggest that the animal surely remembers where it had buried the bone and would likely be willing to offer many other examples to support the claim. But is this what happens?

As it turns out, this is a very difficult question to answer. If we assume that subjective (autonoetic) awareness is the central component of episodic memory, then we are not able to get very far. Much of the evidence for the concept of autonoetic awareness comes by way of verbal reports regarding the subjective state experienced during the act of remembering the past (e.g., remembering vs. knowing). Because we cannot directly ask a nonhuman animal to describe its mental state, the prospect of identifying autonoetic awareness in other species is dim (Clayton et al., 2005). This state of affairs has led some to argue that there should be other means by which to investigate episodic memory in nonhuman animals.

Clayton et al. (2003) suggest that one alternative is to characterize episodic memory in terms of the spatial–temporal information that is encoded about an earlier event (what, where, and when) and the nature by which this information is represented (i.e., as an integrated whole) and utilized. The authors argue that animal studies must consider these behavioral criteria if they are to demonstrate convincing evidence of episodic memory in nonhuman animals. Clayton et al. further review prior attempts using primates, rats, and other animals that fall short of meeting these criteria.

Clayton, Dickinson, and their colleagues have presented several impressive demonstrations of an integrative memory capacity in the western scrub jay (e.g., Clayton and Dickinson, 1998, 1999). In their studies, the scrub jays are given the opportunity to cache both preferable but perishable (e.g., wax worms) and nonpreferable but less perishable (e.g., nuts) foodstuffs (see **Figure 4**). Given that the scrub jays' preferred snack will perish sooner, the birds must remember not only what they stored and where they stored it, but also when the foodstuff had been stored. Although the scrub jays will prefer to search for their favored treat, there is little point if that snack is no longer edible. It appears that the scrub jays are able to integrate these aspects of the original caching episode and search accordingly. That is, the scrub jays are able to appropriately adjust recovery attempts of the differentially perishable caches depending on how long ago they had stored the food items.

**Figure 4** A western scrub-jay caching wax worms.

Even such convincing evidence of an integrated spatial–temporal memory of the past leaves open questions regarding the mental life of this species of bird. As a result, Clayton et al. (2003; Clayton and Dickinson, 1998) refer to this capacity as episodic-like memory, while others question whether this feat represents episodic memory or some other mechanism that may be driven by specific learning algorithms (Suddendorf and Busby, 2003; Suddendorf, 2006; see also Tulving, 2005).

Tulving (2005) has suggested that although mental states cannot be reported by other species, they may in fact be inferred, particularly in the context of mental time travel into the future (e.g., Emery and Clayton, 2001; Dally et al., 2006). Specifically, Tulving argues that comparative studies of episodic memory per se may be futile, in that demonstrations of episodic-like memory in other species may be explained away by simpler mechanisms that need not evoke episodic memory in its true sense (involving autonoetic consciousness). However, it may be possible to construct a situation in which an animal's future-directed behavior may not be attributed to other, simpler means.

Achieving such a situation, however, is no simple matter. A great deal of evidence suggests that even our nearest primitive relatives are incapable of truly future-oriented behavior (for reviews see Roberts, 2002; Suddendorf and Busby, 2003). According to the Bishof-Kohler hypothesis, an animal's foresight is necessarily restricted because it cannot anticipate future needs (for a more in-depth discussion see Suddendorf and Corballis, 1997). For instance, although chimpanzees display preparatory behaviors for future food consumption, it is unclear whether such behaviors indicate foresight beyond the near future (e.g., Boesch and Boesch, 1984; Byrne, 1995). Based on a review of the relevant literature, Roberts (2002) also concluded that higher-order primates appear to be "stuck in time."

Future studies will require clever experimental designs that will allow researchers to examine whether a particular species is able to plan for the future in a manner that is not instigated or maintained by its present motivational state, and in the absence of any immediate benefits associated with a future-directed action (see Mulcahy and Call, 2006; Raby et al., 2007). As it stands, the capacity to mentally represent the personal past and future has only been convincingly demonstrated with human beings (usually over the age of 4 years). Although future research will provide us with a better understanding as to how unique this capacity is to humans, it will likely remain that this capacity holds a special status for humankind (Suddendorf and Corballis, 1997; Tulving, 2002a).

## 2.27.6 Concluding Remarks

As with all concepts of scientific inquiry, episodic memory is an evolving one that is largely shaped through the intricate relationship between data, theory, and available methods of inquiry. The concept of episodic memory started out as a taxonomic distinction that might possess some heuristic usefulness for future research. It has now expanded to encompass a dissociable system of the human brain that enables its owner to accomplish a feat (i.e., becoming autonoetically aware of episodes from one's past) that could not otherwise be possible. Currently, episodic memory represents a concept of great interest to many fields (e.g., clinical psychology, comparative psychology, developmental psychology, experimental psychology, functional brain imaging, neuropsychology, and psychopharmacology). There is little doubt that the continuing accumulation of data from these various areas of research, together with their unique methods of inquiry and furthering technological advancements, will ensure that researchers on the topic will continue to ask new and exciting questions.

## References

Ackerley SS and Benton AL (1947) Report of a case of bilateral frontal lobe defect. *Res. Publ. Assoc. Res. Nerv. Ment. Dis.* 27: 479–504.

Addis DR, Wong AT, and Schacter DL (2007) Remembering the past and imagining the future: Common and distinct neural substrates during event construction and elaboration. *Neuropsychologia* 45: 1363–1377.

Aggleton JP and Brown MW (1999) Episodic memory, amnesia, and the hippocampal-anterior thalamic axis. *Behav. Brain Sci.* 22: 425–444.

Aminoff E, Gronau N, and Bar M (2007) The parahippocampal cortex mediates spatial and nonspatial associations. *Cereb. Cortex* 17: 1497–1503.

Atance CM and Meltzoff AN (2005) My future self: Young children's ability to anticipate and explain future states. *Cogn. Dev.* 20: 341–361.

Atance CM and O'Neill CM (2001) Episodic future thinking. *Trends Cogn Sci 5*(12): 533–539.

Atance CM and O'Neill DK (2005) The emergence of episodic future thinking in humans. *Learn. Motiv.* 36: 126–144.

Bar M (2004) Visual objects in context. *Nat. Rev. Neurosci.* 5: 617–629.

Bar M and Aminoff E (2003) Cortical analysis of context. *Neuron* 38: 347–358.

Barbizet J (1970) *Human Memory and Its Pathology*. San Francisco: Freeman.

Bauer PJ, Hertsgaard LA, and Werenka SS (1995) Effects of experience and reminding on long-term recall in infancy: Remembering not to forget. *J. Exp. Child Psychol.* 59: 260–298.

Bauer PJ and Werenka SS (1995) One- to two-year olds' recall of events: The more expressed, the more impressed. *J. Exp. Child Psychol.* 59: 475–496.

Bekhterev VM (1900) Demonstration eines Gehirns mit Zerstorung der vorderen und inneren Theile der Hirnrinde beider Schlafenlappen. *Neurol. Zbl.* 19: 990–991.

Berntsen D (1996) Involuntary autobiographical memories. *Appl. Cogn. Psychol.* 10: 435–454.

Berntsen D (1998) Voluntary and involuntary access to autobiographical memory. *Memory* 6: 113–141.

Boesch C and Boesch H (1984) Mental map in wild chimpanzees: An analysis of hammer transport for nut cracking. *Primates* 25: 160–170.

Buckner RL (1996) Beyond HERA: Contributions of specific prefrontal brain areas to long-term memory retrieval. *Psychon. Bull. Rev.* 3: 149–158.

Buckner RL (2007) Memory systems: An incentive, not an endpoint. In: Roediger HL III, Dudai Y, and Fitzpatrick SM (eds.) *Science of Memory: Concepts*, pp. 359–366. Oxford: Oxford University Press.

Buckner RL and Carroll DC (2007) Self-projection and the brain. *Trends Cognitive Sci.* 11: 49–57.

Buckner RL and Tulving E (1995) Neuroimaging studies of memory: Theory and recent PET results. In: Boller F and Grafman J (eds.) *Handbook of Neuropsychology*, pp. 439–466. Amsterdam: Elsevier.

Burgess PW, Veitch E, Costello AL, and Shallice T (2000) The cognitive and neuroanatomical correlates of multitasking. *Neuropsychologia* 38: 848–863.

Busby J and Suddendorf T (2005) Recalling yesterday and predicting tomorrow. *Cogn. Dev.* 20: 362–372.

Byrne R (1995) *The Thinking Ape: Evolutionary Origins of Intelligence*. Oxford: Oxford University Press.

Calabrese P, Markowitsch HJ, Durwen HF, et al. (1996) Right temporofrontal cortex as critical locus for ecphory of old episodic memories. *J. Neurol. Neurosurg. Psychiatry* 61: 304–310.

Cermak L and O'Connor M (1983) The anterograde and retrograde retrieval ability of a patient with amnesia due to encephalitis. *Neuropsychologia* 21: 213–234.

Clayton NS and Dickinson A (1998) Episodic-like memory during cache recovery by scrub jays. *Nature* 395: 272–278.

Clayton NS and Dickinson A (1999) Scrub jays (*Aphelocoma coerulescens*) remember when as well as where and what food item they cached. *J. Comp. Psychol.* 113: 403–416.

Clayton NS, Bussey TJ, and Dickinson A (2003) Can animals recall the past and plan for the future? *Nat. Rev. Neurosci.* 4: 685–691.

Crovitz HF and Schiffman H (1974) Frequency of episodic memories as a function of their age. *Bull. Psychon. Soc.* 4(5B): 517–518.

D'Argembeau A and Van der Linden M (2004) Phenomenal characteristics associated with projecting oneself back into the past and forward into the future: Influence of valence and temporal distance. *Conscious. Cogn.* 13: 844–858.

D'Argembeau A and Van der Linden M (2006) Individual differences in the phenomenology of mental time travel: The effect of vivid visual imagery and emotion regulation strategies. *Conscious. Cogn.* 15: 342–350.

Dalla Barba G, Cappelletti JY, Signorini M, and Denes G (1997) Confabulation: Remembering ''another'' past, planning ''another'' future. *Neurocase* 3: 425–436.

Dally JM, Emery NJ, and Clayton NS (2006) Food-caching western scrub-jays keep track of who was watching when. *Science* 312: 1662–1665.

De Renzi E, Lucchelli F, Muggia S, and Spinnler H (1997) Is memory loss without anatomical damage tantamount to a psychogenic deficit? The case of pure retrograde amnesia. *Neuropsychologia* 35: 781–794.

Drummery AB and Newcombe NS (2002) Developmental changes in source memory. *Dev. Sci.* 5: 502–513.

Ebbinghaus H (1885) *Memory: A Contribution to Experimental Psychology*. New York: Dover.

Einstein GO, McDaniel MA, Thomas R, et al. (2005) Multiple processes in prospective memory retrieval: Factors determining monitoring versus spontaneous retrieval. *J. Exp. Psychol. Gen.* 134: 327–342.

Eldridge LL, Knowlton BJ, Furmanski CS, Bookheimer SY, and Engel SA (2000) Remembering episodes: A selective role for the hippocampus during retrieval. *Nat. Neurosci.* 3(11): 1149–1152.

Emery NJ and Clayton NS (2001) Effects of experience and social context on prospective caching strategies by scrub jays. *Nature* 414: 443–446.

Flavell JH (1993) Young children's understanding of thinking and consciousness. *Curr. Dir. Psychol. Sci.* 2: 40–43.

Fletcher PC, Frith CD, Baker SC, Shallice T, Frackowiak R, and Dolan R (1995) The mind's eye-precuneus activation in memory-related imagery. *Neuroimage* 2: 195–200.

Fletcher P, Frith CD, and Rugg MD (1997) Functional neuroanatomy of episodic memory. *Trends Neurosci.* 20: 213–218.

Freeman W and Watts JW (1950) *Pscyhosurgery*, 2nd edn. Springfield, IL: Charles S Thomas.

Fuster JM (1989) *The Prefrontal Cortex. Anatomy, Physiology, and Neuropsychology of the Frontal Lobe*, 2nd edn. New York: Raven.

Gardiner JM (1988) Functional aspects of recollective experience. *Mem. Cognit.* 16: 309–313.

Gardiner JM and Richardson-Klavehn A (2000) Remembering and knowing. In: Tulving E and Craik FIM (eds.) *Oxford Handbook of Memory*, pp. 229–244. Oxford: Oxford University Press.

Ghaem O, Mellet E, Crivello F, et al. (1997) Mental navigation along memorized routes activates the hippocampus, precuneus, and insula. *NeuroReport* 8: 739–744.

Gopnik A and Graf P (1988) Knowing how you know: Young children's ability to identify and remember the sources of their beliefs. *Child Dev.* 59: 1366–1371.

Gopnik A and Slaughter V (1991) Young children's understanding of changes in their mental states. *Child Dev.* 62: 98–110.

Grossi D, Trojano L, Grasso A, and Orsini A (1988) Selective ''semantic amnesia'' after closed-head injury: A case report. *Cortex* 24: 457–464.

Hampton RR (2005) Can rhesus monkeys discriminate between remembering and forgetting? In: Metcalfe HSTJ (ed.) *The Missing Link in Cognition: Origins of Self-Reflective Consciousness*, pp. 272–295. New York: Oxford University Press.

Hassabis D, Kumaran D, Vann SD, and Maguire EA (2007) Patients with hippocampal amnesia cannot imagine new experiences. *Proc. Natl. Acad. Sci. USA* 104: 1726–1731.

Henson RN, Rugg MD, Shallice T, Josephs O, and Dolan RJ (1999) Recollection and familiarity in recognition memory: An event-related functional magnetic resonance imaging study. *J. Neurosci.* 19(10): 3962–3972.

Howe ML and Courage ML (1993) On resolving the enigma of infantile amnesia. *Psychol. Bull.* 113: 305–326.

Howe ML, Courage ML, and Peterson C (1994) how can I remember when ''I'' wasn't there: Long-term retention of traumatic experiences and emergence of the cognitive self. *Conscious. Cogn.* 3: 327–355.

Ingvar DH (1985) ''Memory of the future'': An essay on temporal organization of conscious awareness. *Hum. Neurobiol.* 4(3): 127–136.

Jacoby LL (1991) A process dissociation framework: Separating automatic and intentional uses of memory. *J. Mem. Lang.* 30: 513–541.

James WJ (1890) Memory. In: *The Principles of Psychology*, pp. 643–689. New York: Henry Holt.

Johnson CN and Wellman HM (1980) Children's developing understanding of mental verbs: Remember, know, and guess. *Child Dev.* 51: 1095–1102.

Johnson MK, Hashtroudi S, and Lindsay DS (1993) Source monitoring. *Psychol. Bull.* 114: 3–28.

Johnson MK and Raye CL (1981) Reality monitoring. *Psychol. Rev.* 88: 67–85.

Kapur N (1999) Syndromes of retrograde amnesia: A conceptual and empirical analysis. *Psychol. Bull.* 125: 800–825.

Kitchener EG, Hodges J, and McCarthy R (1998) Acquisition of post-morbid vocabulary and semantic facts in the absence of episodic memory. *Brain* 121: 1313–1327.

Klein SB (2001) A self to remember: A cognitive neuropsychological perspective on how self creates memory and memory creates self. In: Sedikides C and Brewer MB (eds.) *Individual Self, Relational Self, Collective Self*, pp. 25–46. Philadelphia: Psychology Press.

Klein SB, Loftus J, and Kihlstrom JF (2002) Memory and temporal experience: The effects of episodic memory loss on an amnesic patient's ability to remember the past and imagine the future. *Soc. Cogn.* 20(5): 353–379.

Klein SB, German TP, Cosmides L, and Gabriel R (2004) A theory of autobiographical memory: Necessary components and disorders resulting from their loss. *Soc. Cogn.* 22(5): 460–490.

Lepage M, Ghaffar O, Nyberg L, and Tulving E (2000) Prefrontal cortex and episodic memory retrieval mode. *Proc. Natl. Acad. Sci. USA* 97(1): 506–511.

Levine B, Black SE, Cabeza R, et al. (1998) Episodic memory and the self in a case of isolated retrograde amnesia. *Brain* 121: 1951–1973.

Lidz T (1942) The amnesic syndrome. *Arch. Neurol. Psychiatry* 47: 588–605.

Lindsay DS, Johnson MK, and Kwon P (1991) Developmental changes in memory source monitoring. *J. Exp. Child Psychol.* 52: 297–318.

Locke J (1690/1975) *An Essay Concerning Human Understanding*. Nidditch PH (ed.) Oxford: Clarendon Press.

Luria AR (1969) Frontal lobe syndromes. In: Bruyn GW and Vinken PJ (eds.) *Handbook of Clinical Neurology,* vol. 2, pp. 725–757. Amsterdam: North Holland.

Luria AR and Homskya ED (1964) Disturbance in the regulative role of speech with frontal lobe lesions. In: Warren JN and Akert K (ed.) *The Frontal Granular Cortex and Behavior*, pp. 353–371. New York: McGraw-Hill.

Maguire EA (2001) Neuroimaging studies of autobiographical memory. *Philos. Trans. R. Soc. Lond. B* 356: 1441–1451.

Markowitsch HJ, Calabrese P, Neufeld H, Gehlen W, and Durwen HF (1999) Retrograde amnesia for world knowledge and preserved memory for autobiographical events: A case report. *Cortex* 35: 243–252.

McDaniel MA and Einstein GO (2000) Strategic and automatic processes in prospective memory retrieval: A multiprocess framework. *Appl. Cogn. Psychol.* 14: S127–S144.

McDermott KB, Buckner RL, Petersen SE, Kelley WM, and Sanders AL (1999a) Set- and code-specific activation in frontal cortex: An fMRI study of encoding and retrieval of faces and words. *J. Cogn. Neurosci.* 11(6): 631–640.

McDermott KB, Ojemann JG, Petersen SE, et al. (1999b) Direct comparison of episodic encoding and retrieval of words: An event-related fMRI study. *Memory* 7(5–6): 661–678.
McDermott KB, Jones TC, Petersen SE, Lageman SK, and Roediger HL (2000) Retrieval success is accompanied by enhanced activation in anterior prefrontal cortex during recognition memory: An event-related fMRI study. *J. Cogn. Neurosci.* 12: 965–976.
McKenna PJ, Mortimer AM, and Hodges JR (1994) Semantic memory and schizophrenia. In: David AS and Cutting C (eds.) *The Neuropsychology of Schizophrenia*, pp. 163–178. Hove, UK: Erlbaum.
Mellet E, Bricogne S, Tzourio-Mazoyer N, et al. (2000) Neural correlates of topographic mental exploration: The impact of route versus survey perspective learning. *Neuroimage* 12: 588–600.
Mesulam MM (1990) Large-scale neurocognitive networks and distributed processing for attention, language, and memory. *Annu. Rev. Neurol.* 28: 597–613.
Metcalfe J (2000) Metamemory: Theory and data. In: Tulving E and Craik FIM (eds.) *Oxford Handbook of Memory*, pp. 197–211. New York: Oxford University Press.
Miller G (2007) A surprising conection between memory and imagination. *Science* 315: 312.
Mishkin M, Suzuki WA, Gadian DG, and Vargha-Khadem F (1997) Hierarchical organization of cognitive memory. *Philos. Trans. R. Soci. Lond. B* 352: 1461–1467.
Mulcahy NJ and Call J (2006) Apes save tools for future use. *Science* 312: 1038–1040.
Nelson K (1984) The transition from infant to child memory. In: Moscovitch M (ed.) *Infant Memory: Its Relation to Normal and Pathological Memory in Humans and Other Animals,* vol. 26, pp. 1–24. Hillsdale, NJ: Erlbaum.
Nielsen JM (1958) *Memory and Amnesia*. Los Angeles: San Lucas Press.
Nipher FE (1876) Probability of error in writing a series of numbers. *Am. J. Sci. Arts* 12: 79–80.
Nyberg L, Cabeza R, and Tulving E (1996) PET studies of encoding and retrieval: The HERA model. *Psychon. Bull. Rev.* 3: 135–148.
Nyberg L, Persson J, Habib R, et al. (2000) Large scale neurocognitive networks underlying episodic memory. *J. Cogn. Neurosci.* 12: 163–173.
O'Neill DK and Gopnik A (1991) Young children's ability to identify the sources of their beliefs. *Dev. Psychol.* 27: 134–147.
Okuda J, Fujii T, Ohtake H, et al. (2003) Thinking of the future and past: The roles of the frontal pole and the medial temporal lobes. *Neuroimage* 19: 1369–1380.
Perner J and Ruffman T (1995) Episodic memory and autonoetic consciousness: Developmental evidence and a theory of childhood amnesia. *J. Exp. Child Psychol.* 59: 516–548.
Piolino P, Hisland M, Ruffeveille I, Matuszewski V, Jamaque I, and Eustache F (2007) Do school-age children remember or know the personal past? *Conscious. Cogn.* 16: 84–101.
Prince SE, Tsukiura T, Daselaar SM, and Cabeza R (2007) Distinguishing the neural correlates of episodic memory encoding and semantic memory retrieval. *Psychol. Sci.* 18: 144–151.
Raby CR, Alexis DM, Dickinson A, and Clayton NS (2007) Planning for the future by western scrub-jays. *Nature* 445: 919–921.
Rajaram S (1993) Remembering and knowing: Two means of access to the personal past. *Mem. Cogn.* 21: 89–102.
Roberts WA (2002) Are animals stuck in time? *Psychol. Bull.* 128: 473–489.
Robinson JA (1976) Sampling autobiographical memory. *Cogn. Psychol.* 8: 578–595.
Roediger HL (2000) Why retrieval is the key process in understanding human memory. In: Tulving E (ed.) *Memory, Consciousness, and the Brain: The Tallinn Conference*, pp. 52–75. Philadelphia: Psychology Press.
Roediger HL and McDermott KB (1993) Implicit memory in normal human subjects. In: Boller F and Grafman J (eds.) *Handbook of Neuropsychology,* vol. 8, pp. 63–131. Amsterdam: Elsevier.
Roediger HL, Rajaram S, and Srinivas K (1990) Specifying criteria for postulating memory systems. *Ann. NY Acad. Sci.* 608: 572–589; discussion 589–595.
Roediger HL, Buckner RL, and McDermott KB (1999) Components of processing. In: Foster JK and Jelicic M (eds.) *Memory: Systems, Processes, of Function?* pp. 31–65. Oxford: Oxford University Press.
Rosenbaum RS, Priselac S, Kohler S, et al. (2000) Remote spatial memory in an amnesic person with extensive bilateral hippocampal lesions. *Nat. Neurosci.* 3: 1044–1048.
Rosenbaum SR, Ziegler M, Winocur G, Grady CL, and Moscovitch M (2004) ''I have often walked down this street before'': fMRI studies on the hippocampus and other structures during mental navigation of an old environment. *Hippocampus* 14: 826–835.
Rosenbaum RS, Kohler S, Schacter DL, et al. (2005) The case of KC: contributions of a memory-impaired person to memory theory. *Neuropsychologia* 43: 999–1021.
Rugg MD and Allan K (2000) Memory retrieval: An electrophysiological perspective. In: Gazzaniga MS (ed.) *The New Cognitive Neurosciences,* 2nd edn. Cambridge, MA: MIT Press.
Rugg MD and Wilding EL (2000) Retrieval processing and episodic memory. *Trends Cogn. Sci.* 4: 108–115.
Schacter DL (1987) Implicit memory: History and current status. *J. Exp. Psychol. Learn. Mem. Cogn.* 13: 501–518.
Schacter DL and Addis DR (2007a) The cognitive neuroscience of constructive memory: Remembering the past and imagining the future. *Philos. Trans. R. Soc. Lond. B* 362: 773–786.
Schacter DL and Addis DR (2007b) Constructive memory: The ghosts of past and future. *Nature* 445: 27.
Schacter DL, Alpert NM, Savage CR, Rauch SL, and Albert MS (1996) Conscious recollection and the human hippocampal formation: Evidence from positron emission tomography. *Proc. Natl. Acad. Sci. USA* 93: 321–325.
Schacter DL, Bowers J, and Booker J (1989) Intention, awareness, and implicit memory: The retrieval intentionality criterion. In: Lewandowsky S, Dunn JC, and Kirsner K (eds.) *Implicit Memory: Theoretical Issues*, pp. 47–65. Hillsdale, NJ: Lawrence Erlbaum.
Schacter DL, Eich JE, and Tulving E (1978) Richard Semon's theory of memory. *J. Verb. Learn. Verb. Behav.* 17: 721–743.
Schacter DL and Tulving E (1994) What are the memory systems of 1994? In: Schacter DL and Tulving E (eds.) *Memory Systems 1994*, pp. 1–38. Cambridge, MA: MIT Press.
Schacter DL and Wagner AD (1999) Medial temporal lobe activations in fMRI and PET studies of episodic encoding and retrieval. *Hippocampus* 9: 7–24.
Scoville W and Milner B (1957) Loss of recent memory after bilateral hippocampal lesions. *J. Neurol. Neurosurg. Psychiatry* 20: 11–21.
Semon R (1904) *Die Mneme Als Erhaltendes Prinzip im Wechsel des Organishen Geschehens*. Leipzig: Wilhelm Engelmann.
Shallice T (1988) *From Neuropsychology to Mental Structure*. Cambridge: Cambridge University Press.
Shallice T, Fletcher JM, Frith CD, Grasby PM, Frackowiak R, and Dolan R (1994) Brain regions associated with acquisition and retrieval of verbal episodic memory. *Nature* 368: 633–635.
Shannon BJ and Buckner RL (2004) Functional-anatomic correlates of memory retrieval that suggest nontraditional

processing roles for multiple distinct regions within posterior parietal cortex. *J. Neurosci.* 24: 10084–10092.
Sherry DF and Schacter DL (1987) The evolution of multiple memory systems. *Psychol. Rev.* 94: 439–454.
Squire LR (1987) *Memory and Brain*. New York: Oxford University Press.
Stuss DT (1991) Disturbance of self-awareness after frontal system damage. In: Prigatano GP and Schacter DL (eds.) *Awareness of Deficit After Brain Injury*, pp. 63–83. Oxford: Oxford University Press.
Stuss DT and Benson DF (1986) *The Frontal Lobes*. New York: Raven Press.
Suddendorf T (2006) Foresight and evolution of the human mind. *Science* 312: 1006–1007.
Suddendorf T and Busby J (2003) Mental time travel in animals? *Trends Cogn. Sci.* 7: 391–396.
Suddendorf T and Busby J (2005) Making decisions with the future in mind: Developmental and comparative identification of mental time travel. *Learn. Motiv.* 36: 110–125.
Suddendorf T and Corballis MC (1997) Mental time travel and the evolution of the human mind. *Genet. Soc. Gen. Psychol. Monogr.* 123: 133–167.
Svoboda E, McKinnon MC, and Levine B (2006) The functional neuroanatomy of autobiographical memory: A meta-analysis. *Neuropsychologia* 44: 2189–2208.
Szpunar KK and McDermott KB (2007) Remembering the past to imagine the future. *Cerebrum* February. http://www.dana.org/news/cerebrum/detail.aspx?id=5526 [online].
Szpunar KK and McDermott KB (in press) Episodic future thought and its relation to remembering: Evidence from ratings of subjective experience. *Conscious. Cogn*.
Szpunar KK, Watson JM, and McDermott KB (2007) Neural substrates of envisioning the future. *Proc. Natl. Acad. Sci. USA* 104: 642–647.
Taylor M, Esbensen BM, and Bennett RT (1994) Children's understanding of knowledge acquisition: The tendency for children to report that they have always known what they just learned. *Child Dev.* 65: 1581–1604.
Toth JP (2000) Nonconscious forms of human memory. In: Tulving E and Craik FIM (eds.) *Oxford Handbook of Memory*, pp. 245–261. New York: Oxford University Press.
Tulving E (1972) Episodic and semantic memory. In: Tulving E and Donaldson W (eds.) *Organization of Memory*, pp. 381–403. New York: Academic Press.
Tulving E (1976) Ecphoric processes in recall and recognition. In Brown JS (ed.) *Recall and Recognition*, pp. 37–73. New York: Wiley.
Tulving E (1982) Synergistic ecphory in recall and recognition. *Can. J. Psychol.* 36: 130–147.
Tulving E (1983) *Elements of Episodic Memory*. New York: Oxford University Press.
Tulving E (1984) Relations among components and processes of memory. *Behav. Brain Sci.* 7: 257–268.
Tulving E (1985a) How many memory systems are there? *Am. Psychol.* 40: 385–398.
Tulving E (1985b) Memory and consciousness. *Can. Psychol.* 26: 1–12.
Tulving E (1989a) Memory: Performance, knowledge, and experience. *Eur. J. Cogn. Psychol.* 1: 3–26.
Tulving E (1989b) Remembering and knowing the past. *Am. Sci.* 77: 361–367.
Tulving E (1995) Organization of memory: Quo vidas? In: Gazzaniga MS (ed.) *The Cognitive Neurosciences*, pp. 839–847. Cambridge, MA: MIT Press.
Tulving E (2002a) Chronesthesia: Awareness of subjective time. In: Stuss DT and Knight RC (eds.) *Principles of Frontal Lobe Function*, pp. 311–325. New York: Oxford University Press.
Tulving E (2002b) Episodic memory: From mind to brain. *Annu. Rev. Psychol.* 53: 1–25.
Tulving E (2005) Episodic memory and autonoesis: Uniquely human? In Terrace HS and Metcalfe J (ed.) *The Missing Link in Cognition: Origins of Self-Reflective Consciousness*, pp. 3–56. New York: Oxford University Press.
Tulving E and Madigan SA (1970) Memory and verbal learning. *Annu. Rev. Psychol.* 21: 437–484.
Tulving E, Kapur S, Craik FIM, Moscovitch M, and Houle S (1994) Hemispheric encoding/retrieval asymmetry in episodic memory: Positron emission tomography findings. *Proc. Natl. Acad. Sci. USA* 91: 2016–2020.
Tulving E and Markowitsch HJ (1998) Episodic and declarative memory: Role of the hippocampus. *Hippocampus* 8: 198–204.
Valenstein E, Bowers D, Verfaellie M, Heilman KM, Day A, and Watson RT (1987) Retrospenial amnesia. *Brain* 110: 1631–1646.
Vargha-Khadem F, Gadian DG, Watkins KE, Connelly A, Van Paesschen W, and Mishkin M (1997) Differential effects of early hippocampal pathology on episodic and semantic memory. *Science* 277: 376–380.
Viskontas IV, McAndrews MP, and Moscovitch M (2000) Remote episodic memory deficits in patients with unilateral temporal lobe epilepsy and excisions. *J. Neurosci.* 20: 5853–5857.
Wagner AD, Shannon BJ, Kahn I, and Buckner RL (2005) Parietal lobe contributions to episodic memory retrieval. *Trends Cogn. Sci.* 9: 445–453.
Wheeler MA (2000a) Episodic memory and autonoetic consciousness. In: Tulving E and Craik FIM (eds.) *Oxford Handbook of Memory*, pp. 597–608. New York: Oxford University Press.
Wheeler MA (2000b) Varieties of consciousness and memory. In: Tulving E (ed.), *Memory, Consciousness, and the Brain: The Tallinn Conference*, pp. 188–199. Philadelphia: Psychology Press.
Wheeler ME and Buckner RL (2004) Functional-anatomic correlates of remembering and knowing. *Neuroimage* 21: 1337–1349.
Wheeler MA and McMillan CT (2001) Focal retrograde amnesia and the episodic-semantic distinction. *Cogn. Affect. Behav. Neurosci.* 1: 22–37.
Wheeler MA, Stuss DT, and Tulving E (1997) Toward a theory of episodic memory: The frontal lobes and autonoetic consciousness. *Psychol. Bull.* 121: 331–354.
Wimmer H, Hogrefe G-J, and Perner J (1988) Children's understanding of information access as a source of knowledge. *Child Dev.* 59: 386–396.
Yasuda K, Watanabe D, and Ono Y (1997) Dissociation between semantic and autobiographical memory: A case report. *Cortex* 33: 623–638.
Yonelinas AP (2002) The nature of recollection and familiarity: A review of 30 years of research. *J. Mem. Lang.* 46: 441–517.

# 2.28 Semantic Memory

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Semantic memory entails the enormous storehouse of knowledge that all humans have available. To begin with, simply consider the information stored about the words of one's native language. Each of us has approximately 50,000 words stored in our mental dictionary. With each entry, we also have many different dimensions available. For example, with the word 'dog' we have stored information about how to spell it, how to pronounce it, its grammatical category, and the fact that the object the word refers to typically has four legs, is furry, is a common pet, and likes to chase cats (sometimes cars, squirrels, and other rodents), along with additional sensory information about how it feels when petted, the sound produced when it barks, the visual appearance of different types of dogs, emotional responses from past experiences, and much, much more. Of course, our knowledge about words is only the tip of the iceberg of the knowledge we have available. For example, people (both private and public) are a particularly rich source of knowledge. Consider how easy it is to quickly and efficiently retrieve detailed characteristics about John F. Kennedy, Marilyn Monroe, Bill Clinton, a sibling, parent, child, and so on. Indeed, our semantic, encyclopedic knowledge about the world appears limitless.

One concern reflected by the examples above is that semantic memory seems to be all inclusive. In this light, it is useful to contrast it with other forms of memory, and this is precisely what Tulving (1972) did in his classic paper distinguishing semantic and episodic memory. According to Tulving, semantic memory "is a mental thesaurus, organized knowledge a person possesses about words and other verbal symbols, their meaning and referents, about relations among them, and about rules, formulas, and algorithms for the manipulation of these symbols, concepts and relations" (1972, p. 386). In contrast, episodic memory refers to a person's memory for specific events that were personally experienced and remembered. So, the memory for the experience of having breakfast yesterday (e.g., where one was seated, how one felt, the taste of the food, who one was with) would fall under the umbrella of episodic memory, but the fact that eggs, cereal, and toast are typical breakfast foods reflects semantic knowledge. However, as we shall see, there is some controversy regarding where episodic memory ends and semantic memory begins. Indeed, we would argue that semantic memory penetrates all forms of memory, even sensory and working memory (Sperling, 1960; Tulving and Pearlstone, 1966; Baddeley, 2000), because tasks that are assumed to tap into these other types of memory often are influenced by semantic memory.

So, what is indeed unique about semantic memory, and how has this area of research contributed to our understanding of learning and memory in general? One issue that researchers in this area have seriously tackled is the nature of representation, which touches on issues that have long plagued the philosophy of knowledge or epistemology. Specifically, what does it mean to know something? What does it mean to represent the meaning of a word, such as DOG? Is it simply some central tendency of past experiences with DOGS that one has been exposed to (i.e., a prototype DOG), or is there a limited list of primitive semantic features that humans use to capture the meaning of DOG, along with many other concepts and objects? Is the knowledge stored in an abstracted, amodal form that is accessible via different routes or systems, or is all knowledge grounded in specific modalities? For example, the meaning of DOG might be represented by traces laid down by the perceptual motor systems that were engaged when we have interacted with DOGs in the past.

In this chapter, we attempt to provide an overview of the major areas of research addressing the nature of semantic memory, emphasizing the major themes that have historically been at the center of research. Clearly, given the space limitations, the goal here is to introduce the reader to these issues and provide references to more detailed reviews. The vast majority of this work emphasizes behavioral approaches to the study of semantics, but we also touch upon contributions from neuropsychology, neuroimaging, and computational linguistics that have been quite informative recently. We focus on the following major historical developments: (1) the nature of the representation, (2) conceptual development and learning, (3) insights from and limitations of semantic priming studies, (4) interplay between semantic and episodic memory tasks, and (5) cognitive neuroscience constraints afforded by comparisons of different patient populations and recent evidence from neuroimaging studies. For further discussion of this latter area, the interested reader should see Chapter 2.29.

## 2.28.1 Nature of the Representation

Although the question of how one represents knowledge has been around since the time of Aristotle, it is clear that cognitive scientists are still actively pursuing this issue. One approach to representation is that we abstract from experience a prototypical meaning of a concept, and these ideal representations are interconnected to other related representations within a rich network of semantic knowledge. This is the network approach. Another approach is that there is a set of primitive features that we use to define the meaning of words. The meanings of different words and concepts reflect different combinations of these primitive features. This is a feature-based approach. Historically, the distinction between these two approaches has been central to research addressing the nature of semantic memory.

## 2.28.2 Network Approaches

One of the first landmark studies of knowledge representation came from computer science and was based on the important dissertation of A. M. Quillian. Quillian (1968) developed a model of knowledge representation called the Teachable Language Comprehender. A goal of this model was to formulate a working program that allowed efficient access to an enormous amount of information while minimizing redundancy of information in the network. Quillian adopted a hierarchically organized network, a portion of which is displayed in **Figure 1**. As shown, there are two important aspects to the network: nodes and pathways. The nodes in this network are intended to directly represent a concept in semantic memory, so for example, the word BIRD has a node that represents BIRDNESS. These nodes are interconnected in this network via labeled pathways, which are either 'isa' directional pathways or property pathways. Specifically, one can verify that BIRDS are indeed ANIMALS by finding an isa pathway between BIRDS and ANIMALS. Likewise, one could verify that 'A ROBIN BREATHES' by finding the isa pathway between robin and bird, and between bird and animal, and then accessing the property pathway leading to BREATHES from ANIMALS. In this sense, the model was quite economical, because most properties were stored only at the highest level in the network in which most of the lower exemplars included that property. For example, BREATHES would only be stored at the ANIMAL level, and not at the BIRD or CANARY level, thereby minimizing redundancy (and memory storage) in the network. Quillian also recognized that some features may not apply to all exemplars below that level in the network (e.g., ostriches are birds, and birds fly), so in these cases, one needed to include a

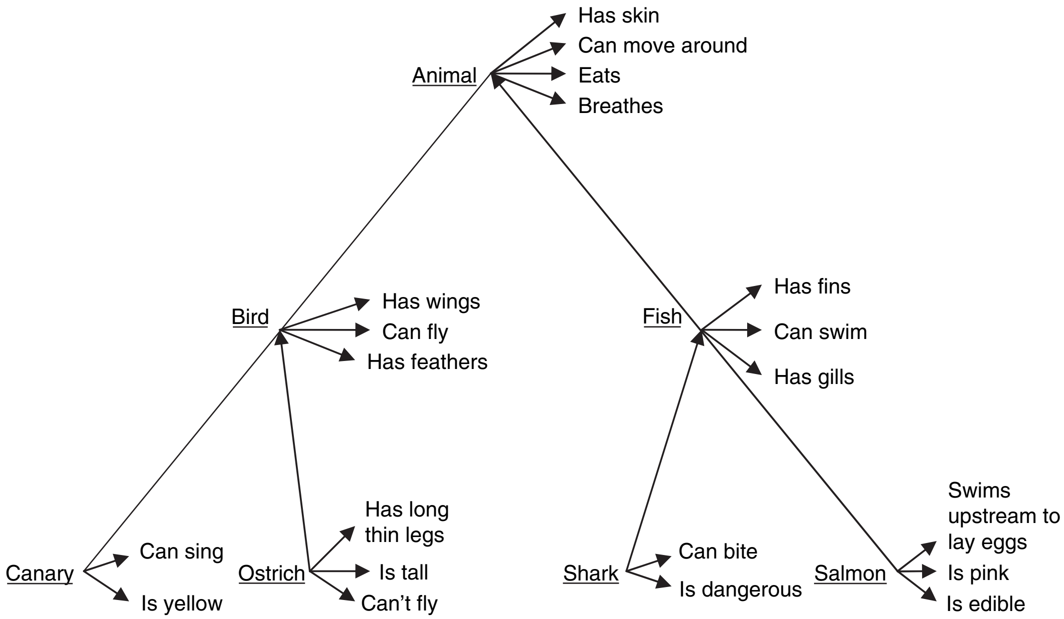


**Figure 1** Hierarchically arranged network. Taken from Collins A and Quillian MR (1969) Retrieval time from semantic memory. *J. Verb. Learn. Verb. Behav.* 8: 240–247.

special property for these concepts (such as CAN'T FLY attached to OSTRICHES).

The economy of the network displayed in Figure 1 does not come without some cost. Specifically, why would one search so deeply in a network to verify a property of a given concept, that is, why would one have to go all the way to the ANIMAL concept to verify that 'CANARIES BREATHE'? It seems more plausible that we would have the property BREATHES directly stored with the CANARY node. Of course, Quillian was not initially interested in how well his network might capture performance in humans, because his goal was to develop a computer model that would be able to verify a multitude of questions about natural categories, within the constraints of precious computer memory available at the time.

Fortunately for cognitive psychologists, Quillian began a collaborative effort with A. Collins to test whether the network model developed by Quillian could indeed predict human performance on a sentence verification task, that is, the speed to verify such sentences as 'A CANARY IS A BIRD'. Remarkably, the Collins and Quillian (1969) study provided evidence that appeared to be highly supportive of the hierarchically organized network structure that Quillian independently developed in artificial intelligence. Specifically, human performance was nicely predicted by how many 'isa' and 'property' pathways one needed to traverse to verify a sentence. The notion is that there was a spreading activation retrieval mechanism that spread across links within the network, and the more links traversed the slower the retrieval time. So, the original evidence appeared to support the counterintuitive prediction that subjects indeed needed to go through the 'CANARY IS A BIRD' link and then the 'BIRD IS AN ANIMAL' link to verify that 'CANARIES BREATHE', because this is where BREATHES is located in the network.

The power of network theory to economically represent the relations among a large amount of information and the confirmation of the counterintuitive predictions via the sentence verification studies by Collins and Quillian (1969) clearly encouraged researchers to investigate the potential of these networks. However, it soon became clear that the initial hierarchically arranged network structure had some limitations. For example, the model encountered some difficulties handling the systematic differences in false reaction times, that is, the finding that correct 'false' responses to 'BUTTERFLIES ARE BIRDS' are slower than responses to 'SPIDERS ARE BIRDS.' Importantly, there was also clear evidence of typicality effects within categories. Specifically, categories have graded structure, that is, some examples of BIRD, such as ROBINS, appear to be better examples than other BIRDS, such as OSTRICHES.

There were numerous attempts to preserve the basic network structure of Collins and Quillian (1969), and indeed, some general models of cognitive performance still include aspects of such network structure. Collins and Loftus (1975) took a major step forward when they developed a network that was not forced into a hierarchical framework. This is displayed in **Figure 2**. As shown, these networks are basically unstructured, with pathways between concepts that are related and the strength of the relationship being reflected by the length of the pathways. Collins and Loftus further proposed that the links between nodes could be dependent on semantic similarity (e.g., items from the same category, such as DOG and CAT, would be linked), or the links could emerge from lexical level factors, such as cooccurrence in the language. Thus, DOG and CAT would be linked because these two items often occur in similar contexts. Because the strength of spreading activation is a function of the distance the activation traversed, typicality effects can be nicely captured in this framework by the length of the pathways. Of course, one might be concerned that such networks are not sufficiently constrained by independent evidence (i.e., if one is slow the pathway must be long). Nevertheless, such networks have been implemented

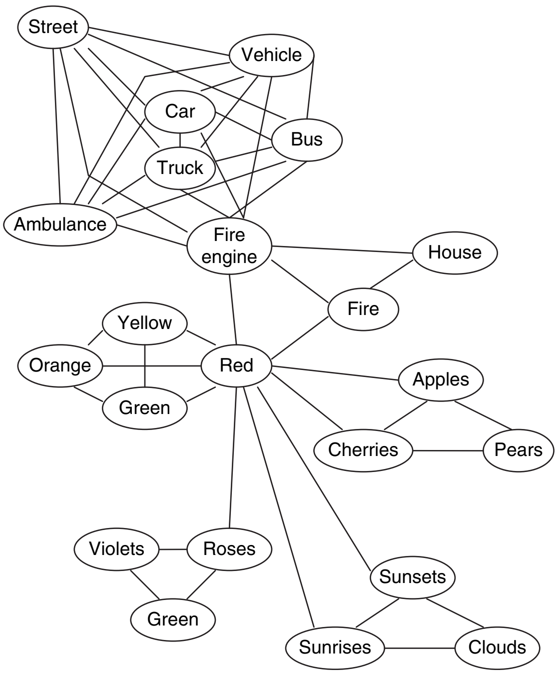


**Figure 2** Semantic network. From Collins AM and Loftus EF (1975) A spreading-activation theory of semantic processing. *Psychol. Rev.* 82: 407–428.

to capture knowledge representation in both semantic and episodic domains (see Anderson, 2000).

More recently, there has been a resurgent interest in a type of network theory. Interestingly, these developments are again driven from fields outside of psychology such as physics (see Albert and Barabasi, 2002) and biology (Jeong et al., 2000). This approach is very principled in nature in that it uses large existing databases to establish the connections across nodes within a network and then uses graph analytic approaches to provide quantitative estimates that capture the nature of the networks. In this light, researchers are not arbitrarily constructing the networks but are allowing the known relations among items within the network to specify the structure of the network. This approach has been used to quantify such diverse networks as the power grid of the Western United States and the neural network of the worm, *C. elegans* (Watts and Strogatz, 1998). Once one has the network established for a given domain (i.e., providing connections between nodes), one can then quantify various characteristics of the network, such as the number of nodes, the number of pathways, the average number of pathways from a node, and the average distance between two nodes. Moreover, there are more sophisticated measures available such as the clustering coefficient, which reflects the probability that two neighbors of a randomly selected node will be neighbors of each other. In this sense, these parameters quantify the characteristics of the targeted network. For example, when looking at such parameters, Watts and Strogatz (1998) found that naturally occurring networks have a substantially higher clustering coefficient and relatively short average distances between nodes compared with randomly generated networks that have the same number of nodes and average connectivity between nodes. This general characteristic of networks is called 'small world' structure. These high clustering coefficients may reflect 'hubs' of connectivity and allow one to access vast amounts of information by retrieving information along the hubs. In popular parlance, such hubs may allow one to capture the six degrees of separation between any two individuals that Milgram (1967) proposed and that has been popularized by the game "six degrees of separation with Kevin Bacon".

What do worms, power grids, and parlor games have to do with semantic memory? Steyvers and Tenenbaum (2005) used three large databases reflecting the meaning of words to construct networks of semantic memory. These included free-association norms (Nelson et al., 1998), WordNet (Miller, 1990), and Roget's Thesaurus (1911). For example, if subjects are likely to produce a word in response to another word in the Nelson et al. free-association norms, then a connection between the two nodes was established in the network. Interestingly, Steyvers and Tenenbaum found that these semantic networks exhibited the same small world structure as other naturally occurring networks; specifically, high-clustering coefficients and a relatively small average path distance between two nodes. As shown in **Figure 3**, if one moves along the hub of highly interconnected nodes, an enormous amount of information becomes readily available via traversing a small number of links.

Of course, it is not a coincidence that naturally occurring networks have small world structure. The seductive conclusion here is that knowledge representation has some systematic similarities across domains. Indeed, Steyvers and Tenenbaum (2005) and others have suggested that such structure reflects central principles in development and representation of knowledge. Specifically, Steyvers and Tenenbaum argue that as the network grows, new nodes are predisposed to attach to existing nodes in a probabilistic manner. It is indeed quite rare that a new meaning of a word is acquired without it being some variation of a preexisting meaning (see Carey, 1978). Hence, across time, nodes that are added to the network will be preferentially attached to existing nodes. This will give rise to a high degree of local clustering, which is a signature of small world network structure. We return to the issue of how concepts develop in a later section.

It is noteworthy that Steyvers and Tenenbaum (2005) have also provided empirical support from their network analyses. For example, they have found that word frequency, or the degree to which a word is encountered in language, and age of acquisition, defined as the average age at which a child learns a given word, effects in naming and lexical decision performance naturally fall from this perspective. Naming and lexical decision are two of the most commonly used word recognition tasks used in research investigating the nature and structure of semantic memory. In naming (or speeded pronunciation), a participant is asked to read a presented stimulus aloud as quickly as possible, whereas in lexical decision, he or she is asked to indicate whether a letter string is a real word or a pseudoword (i.e., a string of letters that does not correspond to the spelling of a real word). In both tasks, the primary dependent measure is response latency. The general assumption is that the speed required to access the pronunciation of a word or to recognize a string of letters reflects processes involved in accessing stored

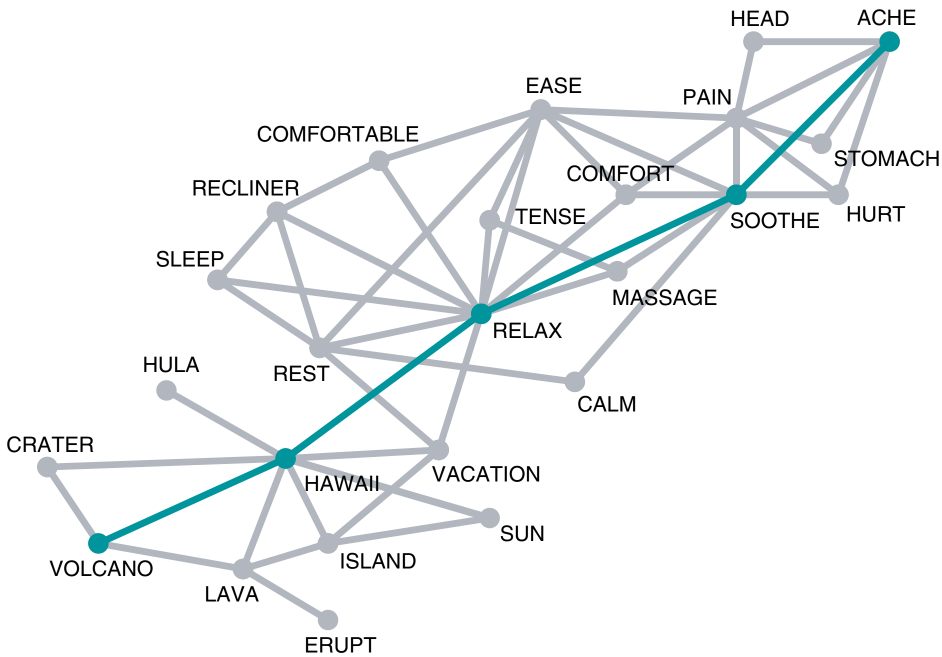


**Figure 3** Segment of small world semantic network. Courtesy of Marc Steyvers.

knowledge about that word. Interestingly, Steyvers and Tenenbaum found a reliable negative correlation between number of connections to a node (semantic centrality) in these networks and response latency, precisely as one might predict, after correlated variables such as word frequency and age of acquisition have been partialed out (also see Balota et al., 2004). Clearly, further work is needed to empirically confirm the utility of these descriptions of semantic structure and the mechanisms by which such networks develop over time. However, the recent graph analytic procedures have taken a significant step toward capturing semantic memory within an empirically verified network.

## 2.28.3 Feature Analytic Approaches

An alternative to concepts being embedded within a rich network structure is an approach wherein meaning is represented as a set of primitive features that are used in various combinations to represent different concepts. Of course, this issue (distributed representation of knowledge, by way of features, vs. a localist representation, via a node to concept relationship) is central to attempts to represent and quantify learning and memory in general. We now turn to a review of the feature-based approaches in semantic memory.

The original Collins and Quillian (1969) research generated a great deal of attention, and soon researchers realized that categories reflected more graded structures than was originally assumed. Specifically, some members of categories are good members (ROBIN for BIRD), whereas other members appear to be relatively poor members (VULTURE for BIRD) but are still definitely members of the category (see Battig and Montague, 1969; Rosch, 1973). In addition, there was a clear influence of goodness of an exemplar on response latencies in the sentence verification task described above. Specifically, good exemplars were faster to verify than poor exemplars, referred to as the typicality effect. The Collins and Quillian hierarchical network model did not have any obvious way of accommodating such degrees of category membership.

Smith et al. (1974) took a quite different approach to accommodate the results from the sentence verification task. They rejected the strong assumptions of network theory and proposed a model that emphasized the notion of critical semantic features in representing the meaning of a word. So, for example, the word BIRD might be represented as animal, two legged, has wings, sings, is small, flies, and so on. There is no hierarchical organization within this model, but concepts reflect lists of critical features. They also distinguished between two classes of features, defining features and characteristic features. Defining features are the necessary features that an exemplar must have to be a member of a category. So, for example, all birds must eat, move, lay eggs, and so forth. On the other hand, characteristic features are features that most, but not all, exemplars have, such as small, flies, sings.

The second important aspect of the Smith et al. (1974) perspective is the emphasis on the decision processes engaged in the classic sentence verification task (see Atkinson and Juola, 1974; Balota and Chumbley, 1984, for similar decision models applied to short-term memory search and lexical decision, respectively). In verifying a sentence such as 'A ROBIN IS A BIRD,' subjects first access all (both defining and characteristic) features associated with ROBIN and all features associated with BIRD. If there is a high degree of overlap in the features, that is, above some criterion, the subject can make a fast 'yes' response. This would be the case in 'A ROBIN IS A BIRD,' since both defining and characteristic features provide a high degree of overlap. On the other hand, some exemplars of a given category may overlap less in characteristic features such as in 'AN OSTRICH IS A BIRD'. Although ostriches are clearly birds, they are not small and do not fly, which are characteristic features of birds. Hence, in such cases, the subject needs to engage in an additional analytic checking process in which only the defining features are compared. This additional check process takes time and so slows response latencies. Hence, the model can naturally capture the typicality effects mentioned above, that is, robins are better exemplars of birds than ostriches, because robins can be verified based on global overlap in features, whereas ostriches must engage the second, more analytic comparison of only the defining features, thereby slowing response latency.

In addition to accounting for typicality effects, the feature analytic model also captured interesting differences in latencies to respond 'no' in the sentence verification task. Specifically, subjects are relatively fast to reject 'A CARP IS A BIRD' compared with 'A BUTTERFLY IS A BIRD.' Carps do not have many overlapping features with birds, and so the subject can quickly reject this item, that is, there is virtually no overlap in features. However, both butterflies and birds typically have wings, are small, and fly. Hence, the subject must engage the additional check of the defining features for 'BUTTERFLY IS A BIRD,' which ultimately leads to slower response latencies, compared with the sentence 'A CARP IS A BIRD.'

Although there were clear successes of the Smith et al. (1974) feature analytic approach, there were also some problems. For example, the model was criticized for the strong distinction between characteristic and defining features. In fact, McCloskey and Glucksberg (1979) provided a single process random walk model that accommodated many of the same results of the original Smith et al. model without postulating a distinction between characteristic and defining features. According to the random walk framework, individuals sample information across time that supports either a yes or no decision. If the features from the subject and predicate match, then movement toward the yes criterion takes place; if the features do not match, then movement toward the no criterion takes place. This model simply assumed that the likelihood of sampling matching feature information for the subject and predicate is greater for typical members than nontypical members, and therefore the response criterion is reached more quickly for typical than nontypical members, thus producing the influence on response latencies. The distinction between single- and dual-process models is a central issue that pervades much of cognitive science.

A second concern about the Smith et al. (1974) model is that they did not directly measure features but, rather, inferred overlap in features based on multidimensional scaling techniques, in which an independent group of subjects simply rated the similarity of words used in the sentence verification experiment. In this way, one could look at the similarity of the words along an N-dimensional space. Interestingly, Osgood et al. (1957) used a similar procedure to tackle the meaning of words in their classic work on the semantic differential. Osgood et al. found that when subjects rated the similarity across words, and these similarity ratings were submitted to multidimensional scaling procedures, there were three major factors that emerged: Evaluative (good–bad), potency (strong–weak), and activity (active–passive). Although clearly this work is provocative, such similarity ratings do not provide a direct measure of the features available for a concept. So, if there are indeed primitive features, it seems necessary to attempt to more directly quantify these features.

McRae and colleagues have been recently attempting to provide such constraints on feature analytic models (McRae et al., 1997; Cree et al., 1999; Cree and McRae, 2003; McRae, 2004; McRae et al., 2005). The goal here is to develop a feature-based computational model implemented in an attractor network capable of capturing the statistical regularities present in semantic domains. The general notion underlying attractor network models is that knowledge is distributed across units (which might be thought of as features) and that the network settles into a steady pattern of activity that reflects the representation of a concept. The conceptual representations that form the basis of semantic knowledge in the model are derived from feature norming data. To collect norms, groups of participants are asked to list features for a number of concepts (e.g., for DOG, participants might list BARKS, FURRY, CHASES CATS, etc.). McRae and colleagues propose that when participants are asked to list features of various basic-level category exemplars (e.g., DOG and APPLE are basic-level concepts from the superordinate category of MAMMALS and FRUIT, respectively), the resulting lists of features reflect the explicit knowledge people have of these concepts. Importantly, McRae does not claim that the nature of the representation consists of a feature list; rather, he argues, the features are derived from repeated multisensory interactions with exemplars of the concept, and in a feature listing task, subjects temporarily create an abstraction for the purpose of listing features that can be verbally described. Currently, feature norming data are available for 541 concrete objects, representing a wide variety of basic-level concepts. Importantly, the model can account for many empirical observations in semantic tasks, as discussed below.

The major assumption implemented by McRae and colleagues' model is that semantic knowledge, as represented by feature lists, involves the statistical averaging of feature correlations among members of similar categories. Features are correlated if they co-occur in basic-level concepts. For example, HAS FUR is highly correlated with HAS FOUR LEGS, as these two features cooccur in numerous exemplars of the mammal category. However, HAS FUR and HAS WINGS have a low (almost nonexistent) correlation, as these two features do not co-occur frequently. The argument is that individuals are highly sensitive to the regularity of the correlations, which are tapped by semantic tasks. As demonstrated by McRae et al. (1999), the strength of the feature correlations predicted feature verification latencies in both human subjects and model simulations, with stronger correlations yielding faster response latencies than weaker correlations when the concept name was presented before the feature name (e.g., DOG-FUR). In addition, the correlation strength interacted with stimulus onset asynchrony (the time between the onset of the concept name and the onset of the feature name, SOA). Specifically, the effect of feature correlations was larger at shorter SOAs, with only high correlations predicting response latencies. However, at longer SOAs, even weakly correlated features influenced response times, indicating that, as more time was allowed for the effects of correlated features to emerge, even the more weakly correlated feature-concept pairs benefited from the shared representation. In another series of studies, McRae et al. (1997) reported that the strength of feature correlations predicted priming for exemplars from the living things domain but not for exemplars from nonliving things domains, for which priming was instead predicted by individual features. This finding is consistent with evidence that, compared to living things, nonliving things tend to have a lower degree of correlated features (also see section 2.28.8.1).

Several interesting extensions of McRae and colleagues' work on the role of features in organizing semantic knowledge have been recently reported. Pexman et al. (2002) examined the role of the number of features associated with a concept and found that items with more features were responded to faster in both naming and lexical decision tasks after a number of other variables known to influence visual word recognition latencies had been factored out. Pexman et al. (2003) reported similar results in a semantic categorization task and in a reading task. These findings were interpreted as supporting the distributed nature of semantic representations in which features are assumed to reflect access to conceptual knowledge, and this information quickly comes on line in isolated word recognition tasks.

In a related vein, there is recent evidence from the categorization literature that categories with richer dimensionalities (i.e., more features and more correlations among features) are easier to learn than categories with fewer dimensions (Hoffman and Murphy, 2006). Thus, rather than resulting in combinatorial explosions that make learning impossible, rich categories with many features lend themselves well to learning – a finding that is nicely mirrored in how people, even very young children, quickly and reliably learn to recognize and classify objects in the world. Indeed, it seems that learning to categorize complex objects, which might be quite similar in terms of features, is something most individuals can do reliably and easily. One concern that arises when one examines the richness of the stimuli in the environment, is the potentially infinite number of features that are available to identify a given concept. In fact, critics of feature-based models have argued that the number of possible feature combinations would result in combinatorial explosion, as knowing even a few features of a category could easily result in an enormous number of ways in which the features could be correlated and integrated (see Murphy, 2002, for a discussion). However, as McRae (2004) notes, two points are relevant in addressing this issue. The first is that the feature correlations tend to influence performance largely in implicit tasks – thus reducing the necessity of explaining how an individual can explicitly use the vast amount of information available. The second point is that the feature vectors that underlie semantic representations are generally sparse. In other words, the absence of a specific feature is uninformative, so, for example, knowing that a dog does not have feathers is relatively uninformative. Thus, although feature-based models might not fully capture the richness of the knowledge that individuals have about concepts, they have been useful in advancing research in the field of semantics.

## 2.28.4 Concept Learning and Categorization

Since semantic memory deals with the nature of representation of meaning, and categories are central to meaning, it is important to at least touch on the area of categorization and how concepts develop. In their classic book, Bruner et al. (1956) emphasized the importance of categorization in organizing what appears to be a limitless database that drives complex human learning and thought. Categorization has been viewed as a fundamental aspect of learning and indeed has been observed early in childhood (Gelman and Markman, 1986) and in other species such as pigeons (Herrnstein et al., 1976). Ross (*See* Chapter 2.29) provides a much more focused discussion of this topic.

One intriguing question that arises when one considers the content of semantic memory concerns the grain size and structure of the representations. In other words, is there a level at which objects in the real world are more or less easy to learn and categorize? One possibility is that the world is initially perceived as a continuum in which there are not separate 'things.' Through repeated interactions with verbal labels or other forms of learning, an individual learns how to discriminate separate objects (e.g., Leach, 1964). This approach places the burden on an extensive and demanding learning process. An alternative approach is that the human cognitive system is ideally suited to detect and recognize objects at a specific grain or level. The assumption that the system is biased toward recognizing specific patterns implies that the process of learning the appropriate verbal labels that refer to specific items in the environment is significantly easier. This problem – how very young children learn that when their mother points to a dog and says 'dog' the referent of the phonological pattern in question refers to an entire object, and not to furry things, things of a certain color, or loosely attached dog parts – has been extensively discussed by Quine (1960).

In an elegant series of experiments, Rosch and colleagues (e.g., Rosch et al., 1976) provided empirical evidence that there is indeed a specific level at which categories of objects are represented that contains the most useful amount of information. For example, identifying a given object as a DOG implies that one recognizes that the specific exemplar is a dog, although it may differ from other dogs one has encountered. Simply knowing something is a dog allows one to draw upon a pool of stored knowledge and experiences to infer appropriate behaviors and interactions with the categorized object. However, knowing the object is an animal is not as informative, given the wide variability among animals. For example, interactions with an elephant are likely to be quite different from those one might have with a spider. Conversely, classifying the exemplar as a Collie or as a German Shepherd does not add a significant amount of inferential power for most purposes.

Rosch et al. (1976) argued that at the basic level, categories are highly informative and can be reliably and easily discriminated from other categories. Exemplars of basic-level categories (e.g., DOGS, BIRDS, CARS, etc.) have many attributes in common, tend to be similar in shape and in how one interacts with them, and allow easy extraction of a prototype or summary representation. The prototype can be accessed and serves as a benchmark against which novel exemplars can be compared: Those that are highly similar to the prototype will be quickly and easily classified as members of the category. Exemplars that differ from the prototype will be recognized as less typical members of a category (e.g., penguins are quite different from many other birds). Hence, typicality effects fall quite nicely from this perspective.

Historically, there has again been some tension between abstract prototype representation and more feature-based approaches. Consider the classic work by Posner and Keele (1968). Although cautious in their interpretation, these researchers reported evidence suggesting that prototypes (in this case a central tendency of dot patterns) were naturally abstracted from stored distortions of that prototype, even though the prototype was never presented for study. They also found that variability across a sufficient number of distortions was critical for abstracting the prototype. These results would appear to support the notion that there is a natural tendency to abstract some representation that is a central tendency of exemplars that share some common elements. So, 'dogness' may be abstracted from the examples of dogs that one encounters. This could suggest that there is indeed a unified representation for dogness.

An alternative approach is that there is nothing unique about these central tendencies but, rather, such representations reflect the similarity of the episodically stored representations in memory. This is a particularly important observation because it suggests that there is a blending of different types of memories, that is, categorical information is simply decontextualized episodic memories. Consider, for example, the classic MINERVA model developed by Hintzman (1986, 1988). In this computational model, each episodic experience lays down a unique trace in memory, which is reflected by a vector of theoretical features. There is no special status of category representations or hierarchical structure. Rather, categorization occurs during retrieval when a probe (the test item) is presented to the system, and the feature vector in the probe stimulus is correlated with all the episodically stored traces. The familiarity of a test probe is a reflection of the strength of the correlations among elements in memory. Because the schema overlaps more with multiple stored representations, that is, it is the central tendency, it will produce a relatively high familiarity signal or strength in a cued recall situation. The importance of the Hintzman approach is that there is no need to directly store central tendencies, as they naturally arise out of the correlation among similar stored traces in the feature vectors. Moreover, as Hintzman argues, there is no need to propose a qualitative distinction between episodic and semantic memories, because both rely on the same memory system, that is, a vast storehouse of individual feature-based episodic traces.

The notion that categories are a reflection of similarity structure across memory traces and can be generated during retrieval clearly has some appeal. Indeed, Barsalou (1985) demonstrated the importance of ad hoc categories that seem to be easily generated from traces that do not inherently have natural category structure; for example, what do photographs, money, children, and pets have in common? On the surface, these items do not appear to be similar – they do not belong to the same taxonomic category, nor do they share many features. However, when given the category label "things to take out of the house in the case of a fire," these items seem to fit quite naturally together because our knowledge base can be easily searched for items that are in the house and are important to us. As Medin (1989) has argued, similarity depends on the theoretical frame that a participant uses to guide a search of memory structures. There appears to be an unlimited number of ways in which similarity can be defined, and hence similarity discovered. For example, lichen and squirrels are similar if one is interested in specifying things in a forest. This brings us to the remarkable context dependency of meaning, and the possibility that meaning is not defined by the stimulus *per se* but is a larger unit involving both the stimulus and the surrounding context. The word DOG in the context of thinking about house pets compared with the word DOG in the context of guard dogs or drug-sniffing dogs probably access quite different interpretations, one in which the focus is on companionship, furriness, and wagging tails, the other in which the more threatening aspects of dogness, such as sharp teeth, are accessed. One might argue that the context activates the relevant set of features, but even this is difficult until one has sufficient constraint on what those features actually are.

## 2.28.5 Grounding Semantics

In part because of the difficulties in defining the critical features used to represent meaning and potential problems with the tractability of prototypes of meaning, several researchers attempted to take novel approaches to the nature of the representations. There are two general approaches that we review in this section. First, because of the increase in computational power, there has been an increased reliance on analyses of large-scale databases to extract similarities across the contexts of words used in various situations. This perspective has some similarity to the exemplar-based approach proposed by Hintzman (1986, 1988) and others described earlier. In this sense, meaning is grounded in the context in which words and objects appear. The second approach is to consider the perceptual motor constraints afforded by humans to help ground semantics, that is, the embodied cognition approach. We review each of these in turn.

### 2.28.5.1 Grounding Semantics in Analyses of Large-Scale Databases

This approach attempts to directly tackle the poverty of the stimulus problem when considering the knowledge that humans have acquired. Indeed, since the days of Plato, philosophers (and more recently psychologists and linguists) have attempted to resolve the paradox of how humans can acquire so much information based on so little input. Specifically, how is it that children learn so much about the referents of words, when to use them, what their syntactic class is, what the relations among referents are, and so on, without explicit instruction? Some have argued (e.g., Pinker, 1994) that the poverty of the stimulus is indeed the reason one needs to build in genetically predisposed language acquisition devices. However, recent approaches to this issue (e.g., Latent Semantic Analysis, or LSA, Landauer and Dumais, 1997; Hyperspace Analogue to Language, or HAL, Burgess and Lund, 1997) have suggested that the stimulus input is not so impoverished as originally assumed. One simply needs more powerful statistical tools to uncover the underlying meaning and the appropriate database.

In an attempt to better understand how rich the stimulus is when embedded in context, Landauer and Dumais (1997) analyzed large corpora of text that included over 4.6 million words taken from an English encyclopedia, a work intended for young students. This encyclopedia included about 30 000 paragraphs reflecting distinct topics. From this, the authors constructed a data matrix that basically included the 60 000 words across the 30 000 paragraphs. Each cell within the matrix reflected the frequency that a given word appeared in a given paragraph. The data matrix was then submitted to a singular value decomposition, which has strong similarities to factor analysis to reduce the data matrix to a limited set of dimensions. Essentially, singular value decomposition extracts a parsimonious representation of the intercorrelations of variables, but, unlike factor analysis, it can be used with matrices of arbitrary shape in which rows and columns represent the words and the contexts in which the words appear. In this case, the authors reduced the matrix to 300 dimensions. These dimensions reflect the intercorrelations that arise across the words from the different texts. So, in some sense the 300 dimensions of a given word will provide information about the similarity to all other words along these 300 dimensions, that is, the degree to which words co-occur in different contexts. The exciting aspect from this data reduction technique is that by using similarity estimates, the model actually performs quite well in capturing the performance of children acquiring language and adults' performance on tests based on introductory textbooks. In this way, the meaning of a word is being captured by all the past experiences with the word, the contexts with which that word (neighbors) occurs, the contexts that the neighbors occur in, and so on.

The remarkable success of LSA, and other similar approaches such as HAL (Burgess and Lund, 1997), provides a possible answer to the poverty of the stimulus problem, that is, when considering the context, the stimulus is indeed very rich. In the past, we simply have not been able to analyze it appropriately. Moreover, the model nicely captures the apparent contextual specificity of meaning in that meaning is defined by all the contexts that words have appeared in and hence will also be constantly changing ever so slightly across subsequent encounters. Finally, the model is indeed quite important because it does not rely on a strong distinction between semantic and episodic memory since it simply reflects past accumulated exposure to language. In this sense, it has some similarity to the Hintzman (1986) model described above.

### 2.28.5.2 Grounding Semantics in Perceptual Motor Systems

An alternative approach that has been receiving considerable recent attention is that meaning can be grounded in perceptual-motor systems (e.g., Barsalou, 1999). Briefly, this perspective is part of the embodied cognition approach that posits that the cognitive system of any organism is constrained by the body in which it is embedded (Wilson, 2002). Thus, cognition (in this case meaning) is not viewed as being separable from perceptual, motor, and proprioceptive systems; rather, it is through the interactions of these systems with the environment that cognition emerges. Furthermore, the type of representations that an organism will develop depends on the structure of the organism itself and how it exists in the world. This approach has its roots in Gibson's (1979) ecological psychology, as it is assumed that structures in the environment afford different interactions to different organisms. It is through repeated interactions with the world that concepts and knowledge emerge. Importantly, the very nature of this knowledge retains its connections to the manner in which it was acquired: Rather than assuming that semantic memory consists of amodal, abstract representations, proponents of embodied approaches argue that representations are grounded in the same systems that permitted their acquisition in the first place (Barsalou et al., 2003).

According to the modality-specific approaches to knowledge, a given concept is stored in adjacent memory systems rather than being abstracted. For example, in Barsolou's (1999) account, knowledge is stored in perceptual symbol systems that emerge through repeated experience interacting with an object or an event. Briefly, Barsalou assumed that when a percept is encountered, selective attention focuses on context-relevant aspects of the percept and allows modal representations to be stored in memory. Repeated interactions with similar events or members of the same category result in the formation of a complex, multimodal representation, and a simulator emerges from these common representations. Simulators are the basic unit of the conceptual system and consist of a frame (which is somewhat similar to a schema), the purpose of which is to integrate the perceptual representations. Simulators provide continuity in the system. Importantly, the representations that are stored include not only modal, perceptual information (e.g., sounds, images, physical characteristics) but also emotional responses, introspective states, and proprioceptive information. Retrieving an exemplar or remembering an event is accomplished by engaging in top-down processing and activating the targeted simulator. Importantly, a given simulator can yield multiple simulations, depending on the organism's goal, the context, and the relevant task demands. For example, different simulations for DOG are possible, such that a different pattern of activity will occur if the warm and furry aspect of dog is relevant or whether the aspect of being a guard or police dog is relevant. Of course, this nicely captures the context sensitivity of meaning. Barsalou (1999) argues that perceptual symbol systems are as powerful and flexible as amodal models, as they are able to implement a complete conceptual system (see also Glenberg and Robertson, 2000).

Evidence in support of modal approaches to semantics can be found in both behavioral and cognitive neuroscience studies. We briefly review some of this evidence here, although a full review of the neuroscience literature is beyond the scope of this chapter (*See* Chapter 3.07 for further discussion of this area). For example, there is evidence from lesion studies that damage to the pathways supporting a specific modality results in impaired performance in categorization and conceptual tasks that rely on that same modality. Specifically, damage to visual pathways generally results in greater impairment in the domain of living things, which tend to rely heavily on visual processes for recognition. Conversely, damage to motor pathways tends to impair knowledge of artifacts and tools, as the primary mode of interaction with these items is through manipulation (see Martin, 2005). Consistent with the lesion data, neuroimaging studies indicate that different regions of the cortex become active when people process different categories. Regions adjacent to primary visual areas become active when categories such as animals are processed (even if the presentation of the stimulus itself is not in the visual modality), whereas regions close to motor areas become active when categories such as tools are processed. These findings have been interpreted as consistent with the hypothesis that people run perceptual-motor simulations when processing conceptual information (Barsalou, 2003).

Pecher et al. (2003) reported evidence from a property verification task indicating that participants were faster in verifying properties in a given modality (e.g., BLENDER-loud) after verifying a different property for a different concept in the same modality (e.g., LEAVES-rustling) than when a modality switch was required (e.g., CRANBERRIES-tart). Pecher et al. argued that the switch cost observed was consistent with the hypothesis that participants ran perceptual simulations to verify the properties (in this case sounds) rather than accessing an amodal semantic system. In a subsequent study, Pecher et al. (2004) observed that when the same concept in a property verification task was paired with two properties from different modalities, errors and latencies increased when verifying the second property. Pecher et al. interpreted this finding as indicating that recent experiences with a concept influence the simulation of the concept. Importantly, researchers have argued that such results are not simply a result of associative strength (i.e., priming) nor of participants engaging in intentional imagery instructions (Barsalou, 2003; Solomon and Barsalou, 2004).

Although the results summarized above are compelling and are supportive of the hypothesis that sensory-motor simulations underlie many semantic tasks, the majority of these studies have examined tasks such as property verification and property generation. The question thus arises of whether the results are somehow an artifact of the task demands, and specifically whether these results reflect the structure of the semantic memory system or whether subjects are explicitly retrieving information as they notice the relations embedded within the experimental context. Glenberg and Kaschak (2002) extended the evidence for embodiment effects to a novel series of tasks that do not appear as susceptible to task demand effects. In these experiments, participants read a brief sentence and judged whether the sentence made sense or not. The critical sentences contained statements that implied motion either toward the participant (e.g., "Nancy gave you the book") or away from the participant (e.g., "You gave the book to Nancy"). Participants responded by moving their hand toward themselves or away from themselves. Glenberg and Kaschak found what they called the action-sentence compatibility effect: When the required response was consistent with the movement implied in the sentence, participants were faster than when the implied motion and the actual physical response were inconsistent. These data appear most consistent with the view that when processing language, people relate the meaning of the linguistic stimulus to action patterns.

## 2.28.6 Measuring Semantic Representations and Processes: Insights from Semantic Priming Studies

As described above, there have been many empirical tools that have been used to provide insights into the nature of semantic memory. For example, as noted earlier, some of the early work by Osgood et al. (1957) attempted to provide leverage on fundamental aspects of meaning via untimed ratings of large sets of words and multidimensional scaling techniques. With the advent of interest in response latencies, researchers turned to sentence verification tasks that dominated much of the early work in the 1970s and 1980s. Although this work has clearly been influential, the explicit demands of such tasks (e.g., explicitly asking subjects to verify the meaningfulness of subject-predicate relations) led some researchers in search of alternative ways to measure both structure and retrieval processes from semantic memory. There was accumulating interest in automatic processes (LaBerge and Samuels, 1974; Posner and Snyder, 1975) that presumably captured the modular architecture of the human processing system (Fodor, 1983), and there was an emphasis on indirect measures of structure and process. Hence, researchers turned to semantic priming paradigms.

Meyer and Schvaneveldt (1971) are typically regarded as reporting the first semantic priming study. In this study, subjects were asked to make lexical decisions (word-nonword decisions) to pairs of stimuli. The subjects' task was to respond yes only if both strings were words. The interesting finding here was that subjects were faster to respond yes when the words were semantically related (DOCTOR NURSE), compared with when they were unrelated (BREAD NURSE). This pattern was quite intriguing because subjects did not need to access the semantic relation between the two words to make the word/nonword decisions. Hence, this may reflect a relatively pure measure of the underlying structure and retrieval processes, uncontaminated by explicit task demands. Moreover, the development of this paradigm was quite important because researchers thought it may tap the spreading activation processes that was so central to theoretical developments at the time.

The research on semantic priming took a significant leap forward with the dissertation work of Neely (1977), who used a framework developed by Posner and Snyder (1975) to decouple the attentional strategic use of the prime-target relations from a more automatic component. In this study, subjects only made lexical decisions to the target, and subjects were given explicit instructions of how to use the prime information. For example, in one condition, subjects were told that when they received the prime BODY, they should think of building parts (Shift condition), whereas in a different condition, subjects were told that when they received the category prime BIRD, they should think of birds (Nonshift condition). Neely varied the time available to process the prime before the target was presented by using SOAs ranging from 250 to 2000 ms. The important finding here is that the instructions of what to expect had no influence on the priming effects at the short SOA (i.e., priming occurred if the prime and target had a semantic relationship, independent of expectancies), but they did have a large effect at the long SOA, when subjects had time to engage an attentional mechanism (i.e., the priming effects were totally dependent on what subjects were told to expect, independent of the preexisting relationship). Hence, Neely argued that the short SOA data reflected pure automatic measures of the semantic structure and retrieval processes and could be used as a paradigm to exploit the nature of such semantic representations.

A full review of the rich semantic priming literature is clearly beyond the scope of the present chapter (see Neely, 1991; Lucas, 2000; Hutchison, 2003, for excellent discussions of the methodological and theoretical frameworks). However, it is useful to highlight a few issues that have been particularly relevant to the current discussion. First, there is some controversy regarding the types of prime-target relations that produce priming effects. For example, returning to the initial observation by Meyer and Schvaneveldt (1971), one might ask if DOCTOR and NURSE are related because they share some primitive semantic features or are simply related because they are likely to co-occur in the same contexts in the language. Of course, this distinction reflects back on core assumptions regarding the nature of semantic information, since models like LSA might capture priming between DOCTOR and NURSE, simply because the two words are likely to cooccur in common contexts. Researchers have attempted to address this by selecting items that vary on only one dimension (see, e.g., Fischler, 1977; Lupker, 1984; Thompson-Schill et al., 1998). Here, semantics is most typically defined by category membership (e.g., DOG and CAT are both semantically related and associatively related, whereas MOUSE and CHEESE are only associatively related). Hines et al. (1986), De Mornay Davies (1998), and Thompson-Schill et al. (1998) have all argued that priming is caused by semantic feature overlap because of results indicating priming only for words that shared semantic overlap versus those did not, when associative strength was controlled. However, Hutchison (2003) has recently argued that the studies that have provided evidence for pure semantic effects (i.e., while equating for associative strength), actually have not adequately controlled for associative strength based on the Nelson et al. (1998) free-association norms. Clearly, equating items on one dimension (associative strength or semantic overlap) while manipulating the other dimension is more difficult than initially assumed. In this light, it is interesting to note that two recent review papers have come to different conclusions regarding the role of semantics in semantic priming based on such item selection studies. Lucas (2000) argued that there was clear evidence of pure semantic effects, as opposed to associative effects, whereas Hutchison (2003) was relatively more skeptical about the conclusions from the available literature.

Balota and Paul (1996) took a different approach to the meaning versus associative influence in priming via a study of multiple primes, instantiating the conditions displayed in **Table 1**. As one can see, the primes were either both related, first related, second related, or both unrelated to the targets, and the targets could either be homographic words with distinct meanings (e.g., ORGAN) or a nonhomographic words (e.g., STRIPES). As one can see, the primes were related to the targets at both the semantic and associative level for the nonhomographs (e.g., LION and STRIPES are both related to TIGER at the associative and semantic level), but for the homographs the primes were related to the targets at only the associative level (e.g., PIANO and KIDNEY are only related to ORGAN at the associative level, since KIDNEY and PIANO are different meanings of ORGAN). Thus, one could compare priming effects in conditions in which primes converged on the same meaning of the target (nonhomographs) and priming effects where the primes diverged on different

**Table 1** Prime-target conditions from the Balota and Paul (1996) multiprime study

| *Nonhomographs* | | | |
|---|---|---|---|
| *Condition* | *Prime 1* | *Prime 2* | *Target* |
| Related–related | LION | TIGER | STRIPES |
| Unrelated–related | FUEL | TIGER | STRIPES |
| Related–unrelated | LION | SHUTTER | STRIPES |
| Unrelated–unrelated | FUEL | SHUTTER | STRIPES |
| *Homographs* | | | |
| *Condition* | *Prime 1* | *Prime 2* | *Target* |
| Related–related | KIDNEY | PIANO | ORGAN |
| Unrelated–related | WAGON | PIANO | ORGAN |
| Related–unrelated | KIDNEY | SODA | ORGAN |
| Unrelated–unrelated | WAGON | SODA | ORGAN |

Balota DA and Paul ST (1996) Summation of activation: Evidence from multiple primes that converge and diverge within semantic memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 22: 827–845.

meanings (homographs). The results from four experiments indicated that the primes produced clear additive effects, that is, priming effects from the single related prime conditions nicely summated to predict the priming effects from the double related prime conditions for both homographs and nonhomographs, suggesting that the effects were most likely a result of associative level information. Only when subjects directed attention to the meaning of the word, via speeded semantic decisions, was there any evidence of the predicted difference between the two conditions. Hence, these results seem to be supportive of the notion that standard semantic priming effects are likely to be the result of associative-level connections instead of meaning-based semantic information. Of course, the interesting theoretical question is how much of our semantic knowledge typically used is caused by overlap in the contexts in which items are stored as opposed to abstracted rich semantic representations.

Hutchison (2003) notes two further findings that would appear to be supportive of associative influences underlying semantic priming effects. First, one can find evidence of episodic priming in lexical decision and speeded word naming tasks. In these studies, subjects study unrelated words such as (CITY-GRASS) and are later presented prime-target pairs in a standard lexical decision study. The interesting finding here is that one can obtain priming effects in such studies, compared to an unrelated/unstudied pair of words (see McKoon and Ratcliff, 1979). Thus, the semantic priming effects obtained in word recognition tasks can also be produced via purely associative information that develops within a single study exposure. However, it should be noted here that there is some question regarding the locus of such priming effects and that one needs to be especially cautious in making inferences from the episodic priming paradigm and the role of task-specific strategic operations (see, e.g., Neely and Durgunoglu, 1985; Durgunoglu and Neely, 1987; Spieler and Balota, 1996; Pecher and Raajmakers, 1999; Faust et al., 2001).

The second pattern of results that Hutchison (2003) notes as being critical to the associative account of semantic priming effects is mediated priming. In these situations, the prime (LION) is related to the target (STRIPES) only through a nonpresented mediator (TIGER). So, the question is whether one can obtain priming from LION to STRIPES, even though these two words appear to be semantically unrelated. Although de Groot (1983) failed to obtain mediated priming effects in the lexical decision task, Balota and Lorch (1986) argued that this may have resulted from the task-specific characteristics of this task. Hence, Balota and Lorch used a speeded pronunciation task and found clear evidence of mediated priming. Evidence for mediated priming has also now been found in versions of the lexical decision task designed to minimize task-specific operations (e.g., McNamara and Altarriba, 1988; McKoon and Ratcliff, 1992; Sayette et al., 1996; Livesay and Burgess, 1998). Of course, it is unclear what semantic features overlap between LION and STRIPES, and so these results would appear to be more consistent with an associative network model, in which there is a relationship between LION and TIGER and between TIGER and STRIPES, along with a spreading activation retrieval mechanism (see McKoon and Ratcliff, 1992; Chwilla and Kolk, 2002, for alternative accounts of the retrieval mechanism).

In sum, although the semantic priming paradigm has been critical in measuring retrieval mechanisms from memory, the argument that these effects reflect amodal semantic representations that are distinct from associative information has some difficulty accommodating the results from multiprime studies, episodic priming studies, and mediated priming studies. As noted earlier, there are available models of semantic memory (e.g., Burgess and Lund, 1997, HAL; Landauer and Dumais, 1997, LSA) and categorization (e.g., Hintzman, 1996, MINERVA) that would strongly support the associative contributions to performance in such tasks and, indeed, question the strong distinction between semantic and episodic memory systems. Hence, this perspective predicts a strong interplay between the systems. We now turn to a brief discussion of the evidence that directly addresses such an interplay.

## 2.28.7 The Interplay Between Semantics and Episodic Memory

Memory researchers have long understood the influence of preexisting meaning on learning and memory performance (see Crowder, 1976, for a review). Indeed, in his original memory manifesto, Ebbinghaus (1885) was quite worried about this influence and so purposefully stripped away meaning from the to-be-learned materials by presenting meaningless trigrams (KOL) for acquisition. Of course, semantics has penetrated episodic memory research in measures of category clustering (see Bousfield, 1953; Cofer et al., 1966; Bruce and Fagan, 1970), retrieval-induced inhibition (see Anderson et al., 1994), and release from proactive interference (see Wickens, 1973), among many other paradigms. Indeed, the interplay between preexisting knowledge and recall performance was the centerpiece of the classic work by Bartlett (1932). Researchers realized that even consonant–vowel–consonant trigrams were not meaningless (see Hoffman et al., 1987). At this level, one might even question what it would mean to episodically store in memory totally meaningless information.

One place where researchers have attempted to look at the interplay between semantic and episodic structures is within the episodic priming paradigm described earlier. In these studies, participants receive pairs of unrelated words for study and then are later given prime-target pairs that have either been paired together or not during the earlier acquisition phase. For example, Neely and Durgunoglu (1985) investigated the influence of studying previous pairs of words and word–nonword combinations on both lexical decision performance and episodic recognition performance (also see Durgunoglu and Neely, 1987). Although there were clear differences between the tasks in the pattern of priming effects (suggesting dissociable effects across the two systems), there were also some intriguing similarities. For example, there was evidence of inhibition at a short prime-target SOA (150 ms) in both the episodic recognition task and the lexical decision task from semantically related primes that were in the initial studied list but were not paired with the target. It appeared as if this additional semantic association had to be suppressed in order for subjects to make both the episodic recognition decision and the lexical decision. The finding that this effect occurred at the short SOA also suggests that it may have been outside the attentional control of the participant.

The power of preexisting semantic representations on episodic tasks has recently taken a substantial leap forward with the publication of an important paper by Roediger and McDermott (1995), which revisited an earlier paper published by Deese (1959). This has now become know as the DRM (after Deese, Roediger, and McDermott) paradigm. The procedure typically used in such studies involves presenting a list of 10–15 words for study (REST, AWAKE, DREAM, PILLOW, BED, etc.) that are highly related to a critical nonpresented item (SLEEP). The powerful memory illusion here is that subjects are just as likely to recall (or recognize) the critical nonpresented item (SLEEP) as items that were actually presented. Moreover, when given remember/know judgments (Tulving, 1985), participants often give the critical nonpresented item remember judgments that presumably tapped detailed episodic recollective experience. It is as if the strong preexisting semantic memory structure is so powerful that it overwhelms the episodic study experience.

It should not be surprising that many of the same issues that have played out in the semantic memory research have also played out in the false memory research. Indeed, one model in this area is the activation monitoring (AM) framework (e.g., Roediger et al., 2001a), which suggests that subjects sometimes confuse the activation that is produced by spreading activation that converges on the critical nonpresented item (much akin to the Collins and Loftus, 1975) with the activation resulting from the study event. This framework attempts to keep separate the episodic and semantic systems but also shows how such systems can interact. In contrast, Arndt and Hirshman (1998) have used the Hintzman (1986) MINERVA framework to accommodate the DRM effect by relying on the similarity of the vectors of the individually stored words and the critical nonpresented items. As noted above, the MINERVA framework does not make a strong distinction between episodic and semantic systems. Moreover, the MINERVA model is more a feature-based model, whereas the AM framework *a priori* would appear more akin to a prototype model, but no strong claims have been made along this dimension. A further distinction between the AM framework and the MINERVA approach concerns the relative contributions of backward associative strength (BAS, or the probability that a list item will elicit the target, or critical lure, on a free-association task) and forward associative strength (FAS, or the probability the critical lure will elicit a list item in such a task). According to AM accounts, the critical variable is expected to be BAS, as the activation flows from the list items to the critical lure. However, according to MINERVA, FAS should be more important, as the similarity between the probe (i.e., the critical lure) and the stored episodes (i.e., the list items) should be a more powerful determinant of memory performance. Results from a multiple regression analysis reported by Roediger et al. (2001b) indicated that, in the DRM paradigm, BAS was the better predictor, thus supporting the AM framework. (We thank Roddy Roediger for pointing this out.)

The question of the nature of the representation (i.e., associative vs semantic) underlying these powerful memory illusions has also been studied. For example, Hutchison and Balota (2005) recently utilized the summation paradigm developed by Balota and Paul (1996), described earlier, to examine whether the DRM effect reflects meaning-based semantic information or could also be accommodated by primarily assuming an associative level information. Hence, in this study, subjects studied lists of words that were related to one meaning or related to two different meanings of a critical nonpresented homograph (e.g., the season meaning of FALL or the accident meaning of FALL). In addition, there were standard DRM lists that only included words that were related to the same meaning of a critical nonpresented word (e.g., such as SLEEP). Consistent with the Balota and Paul results, the results from both recall and recognition tests indicated that there was no difference in the pattern of false memory for study lists that converged on the same meaning (standard DRM lists) of the critical nonpresented items and lists that diverged on different meanings (homograph lists) of the critical nonpresented items. However, when subjects were required to explicitly make gist-based responses and directly access the meaning of the list, that is, is this word related to the studied list, there was clear (and expected) difference between homograph and nonhomograph lists. Hutchison and Balota argued that although rich networks develop through strategic use of meaning during encoding and retrieval, the activation processes resulting from the studied information seem to primarily reflect implicit associative information and do not demand rich meaning-based analysis.

There is little doubt that what we store in memory is a reflection of the knowledge base that we already have in memory, which molds the engram. Hence, as noted earlier, semantic memories may be episodic memories that have lost the contextual information across time because of repeated exposures. It is unlikely that a 50-year-old remembers the details of hearing the Rolling Stones' "Satisfaction" for the first time, but it is likely that, soon after that original experience, one would indeed have vivid episodic details, such as where one was, who one was with, and so on. Although this unitary memory system approach clearly has some value (e.g., McKoon et al., 1986), it is also the case that there is some powerful evidence from cognitive neuroscience that supports a stronger distinction.

## 2.28.8 Representation and Distinctions: Evidence from Neuropsychology

Evidence for the distinction of multiple memory systems has come from studies of patients with localized lesions that produce strong dissociations in behavior. For example, the classic case of HM (see Scoville and Milner, 1957) indicated that damage to the hippocampus resulted in impairment of the storage of new episodic memories, whereas semantic knowledge appeared to be relatively intact (but see MacKay et al., 1998). Hence, one might be overly concerned about the controversy from the behavioral studies regarding the distinct nature of semantic and episodic memory systems. However, there are additional neuropsychological cases that are indeed quite informative about the actual nature of semantic representations.

### 2.28.8.1 Category-Specific Deficits

There have now been numerous cases of individuals who have a specific lesion to the brain and appear to have localized category-specific deficits. For example, there have been individuals who have difficulty identifying items from natural categories (e.g., animals, birds, fruits, etc.) but have a relatively preserved ability to identify items from artificial categories (e.g., clothing, tools, furniture). At first glance, such results would appear to suggest that certain categories are represented in distinct neural tissue that have or have not been disrupted by the lesion. Such a pattern may also be consistent with a localized representation of meaning instead of a distributed feature-based representation in which all concepts share vectors of the same set of primitive features.

Unfortunately, however, the interpretation of impaired performance on natural categories and intact performance on artificial categories has been controversial. For example, such deficits could occur at various stages in the information flow from discriminating visually similar items (e.g., Riddoch and Humphreys, 1987) to problems retrieving the appropriate name of an object (e.g., Hart et al., 1985). Such accounts do not rely on the meaning of the categories but suggest that such deficits may reflect correlated dimensions (e.g., difficulty of the visual discrimination) that differ between natural and artificial categories. In this light, it is particularly important that there have been cases that have shown the opposite pattern. For example, Sacchett and Humphreys (1992) reported an intriguing case that shows disruption of the performance on artificial categories and body parts but relatively preserved performance on natural categories. They argued that one possible reason for this pattern is that this individual had a deficit in representing functional features, which are more relevant to artifactual representations and body parts than natural categories such as fruits and vegetables. Whatever the ultimate explanation of these category-specific deficits, this work has been informative in providing a better understanding of how members within categories may differ on distinct dimensions.

In a similar vein, one hypothesis that has been suggested to explain domain differences in category-specific deficits is the sensory/functional hypothesis (Warrington and McCarthy, 1987; Farah and McClelland, 1991; Caramazza and Shelton, 1998). According to this proposal, natural categories such as animals depend heavily on perceptual information (especially on visual discriminations) for identification and discrimination. Conversely, functional information is more important for recognition of artifacts, such as tools. Thus, damage to regions of sensory cortex is expected to result in selective impairment of natural kinds, whereas damage to regions in or adjacent to motor cortex would result in impairment in artifacts. Although compelling, this view is not endorsed by all researchers. Caramazza and colleagues, in particular, have argued that the sensory/functional hypothesis fails to account for some of the patterns of deficits observed and some of the finer-grain distinctions. In particular, it is difficult for this model to account for the selective sparing or impairment of fruits and vegetables, body parts, and musical instruments that have been reported (see Capitani et al., 2003, for a recent review). Thus, the question of whether and how the type of knowledge that is most critical for supporting the representation of a particular domain is involved in category-specific deficits remains open.

To address this controversy, Cree and McRae (2003) extended the sensory/functional hypothesis to include a broader range of types of knowledge. They developed a brain region taxonomy that included nine different forms of knowledge, including sensory/perceptual in all modalities (vision, taste, audition, etc.), functional, and encyclopedic. Encyclopedic features included information about items such as LIVES IN AFRICA for ELEPHANT – in other words, information that likely was learned and not experienced directly. Cree and McRae then developed a nine-dimensional representation for the 541 concepts for which they had norming data and estimated the salience of each type of knowledge for each object and each category. In a series of cluster analyses, Cree and McRae found that the knowledge types nicely predicted the tripartite distinction between living things, artifacts, and fruits and vegetables reported in several neuropsychological case studies. In addition, Cree and McRae examined several distributional statistics, including the number of distinguishing and distinctive features and similarity to obtain a measure of confusability (i.e., the extent to which a given concept might be confused with another concept from the same category). The categories they examined did appear to be differentially sensitive to these measures, and the implemented model reflected patterns of impairment observed in patients. They concluded that knowledge type does underlie the organization of conceptual representations and that selective impairment in a particular brain region involved in maintaining such knowledge can result in the observed patterns of impairment in patients with category-specific deficits. Although many questions remain, it is clear that evidence from individuals with category-specific deficits has provided considerable insight into both the nature of category representation and the underlying neural representations.

### 2.28.8.2 Semantic Dementia

The most common form of dementing illness is dementia of the Alzheimer type (DAT). However, there is also a relatively rare and distinct dementia, referred to as semantic dementia (SD), which overlaps with DAT in features such as insidious onset and gradual deterioration of comprehension and word-finding ability. SD is a variant of frontal temporal dementia and typically involves one or both of the anterior portions of the temporal lobes. The consensus criteria for SD (Hodges et al., 1992) include impairment in semantic memory causing anomia, deficits in both spoken and written word comprehension, a reading pattern consistent with surface dyslexia (i.e., impairment in reading exception words such as PINT but preserved reading of regular words and nonwords that follow standard spelling to sound rules, such as NUST), impoverished knowledge about objects and/or people with relative sparing of phonological and syntactic components of speech output, and perceptual and nonverbal problem solving skills. These individuals are often quite fluent, but their speech is relatively limited in conveying meaning. They are particularly poor at picture naming and understanding the relations among objects. For example, the Pyramids and Palm Trees test developed by Howard and Patterson (1992) involves selecting which of two items (e.g., a palm tree or a fir tree) is most similar to a third item (e.g., a pyramid). Individuals with SD are particularly poor at this task and so would appear to have a breakdown in the representations of the knowledge structures.

An interesting dissociation has been made between SD individuals and DAT individuals. In particular, Simons et al. (2002) recently found a double dissociation, wherein individuals with SD produced poorer picture naming than individuals with DAT; however, individuals with SD produced better performance than individuals with DAT on a later episodic recognition test of these very same pictures (also see Gold et al., 2005). Clearly, the selective impairment across these two groups of participants is consistent with distinct types of information driving these tasks. Of course, one must be cautious about the implications even from this study, because it is unlikely that either task is a process-pure measure of episodic and semantic memory (see Jacoby, 1991), but clearly these results are very intriguing.

Recently, Rogers et al. (2004) proposed a model of semantic memory that maintains strong connections to modality-specific systems in terms of both inputs and outputs and has been particularly useful in accommodating the deficits observed in SD. This model has some interesting parallels to Barsalou's (1999) proposal, in that it assumes that semantic memory is grounded in perception and action networks. In addition, like the model proposed by McRae et al. (1997), Rogers et al. suggest that the system is sensitive to statistical regularities, and these regularities are what underlie the development of semantics. The particular contribution of Rogers et al.'s model, however, is that although semantic representations are grounded in perception–action modality-specific systems, the statistical learning mechanism allows the emergence of abstract semantic representations. Importantly, inputs to semantics are mediated by perceptual representations that are modality specific, and as a result, the content of semantic memory relies on the same neural tissue that supports encoding. However, different from Barsalou and colleagues' account, Rogers et al. do suggest that there is a domain-general, abstracted representation that emerges from cross-modal mappings. Thus, although the system relies on perceptual inputs, the abstract representations can capture cross-modality similarities and structures to give rise to semantic memory.

Rogers et al. (2004) implemented a simple version of their model using a parallel distributed-processing approach in which visual features provided the perceptual input and are allowed to interact in training with verbal descriptors through a mediating semantic level. Importantly, the semantic representations emerge through the course of training as the network learns the mappings between units at the visual and verbal levels. The units the model was trained on consisted of verbal and visual features generated in separate norming sessions. Once training was complete, several simulations were reported in which the model was progressively damaged in a way that was thought to mimic varying levels of impairment observed in individuals with SD. Overall, the model nicely captured the patterns of performance of the patients. Specifically, one pattern often observed in SD is a tendency to overregularize conceptual knowledge. For example, individuals might refer to all exemplars of a category using the superordinate label or a single label that is high in frequency (e.g., calling a DOG an ANIMAL or a ZEBRA a HORSE). This is possibly a result of the progressive failure in retrieving idiosyncratic information that serves to distinguish exemplars, such that only the central tendency (e.g., a prototype or most typical exemplar) remains accessible. Thus, less common items might take on the attributes of higher-frequency exemplars. The model displayed similar patterns of generalization as the SD individuals, a finding explained in terms of changes in attractor dynamics that resulted in the relative sparing of features and attributes shared by many exemplars but a loss of more distinctive features. This model provides an interesting account of semantic memory and the deficits observed in individuals with SD, one in which both perceptually based information and abstracted representations interact to give rise to knowledge of the world.

## 2.28.9 Neuroimaging

Investigations into the nature of semantic memory have benefited from recent advances in technology that allow investigators to examine online processing of information in the human brain. For example, positron emission technology (PET) and functional magnetic resonance imaging (fMRI) allow one to measure correlates of neural activity *in vivo* as individuals are engaged in semantic tasks (see Logothetis and Wandell, 2004). Although a full review of the substantial contributions of neuroimaging data to the questions pertaining to semantics is beyond the scope of this chapter (*See* Chapter 3.07 for a review), we briefly examine some of the major findings that have helped constrain recent theorizing about the nature and locus of semantic representations. Two major brain regions have been identified through neuroimaging studies: left prefrontal cortex (LPC) and areas within the temporal lobes, particularly in the left hemisphere.

The first study to report neuroimaging data relevant to semantic memory was conducted by Petersen et al. (1988), who used PET techniques to localize activation patterns specific to semantic tasks. Subjects were asked to generate action verbs upon presentation of a concrete object noun, and activity during this task was compared with the activity occurring during silent reading of the words. Petersen et al. reported significant patterns of activity in LPC, a finding that has since been replicated and extended to other types of attributes. Martin et al. (1995) extended this work to show that the specific attribute to be retrieved yielded different patterns of activation. Specifically, the locus of activation involved in attribute retrieval tends to be in close proximity to the neural regions that are involved in perception of the specific attributes. Thus, retrieval of visual information, such as color, tends to activate regions adjacent to the regions involved in color perception, whereas retrieval of functional information results in activation of areas adjacent to motor cortex. These findings mesh nicely with the perceptual/motor notions of representation in semantic memory reviewed above (e.g., Barsalou, 1999; Rogers et al., 2004). In addition, Roskies et al. (2001) reported that not only were regions in lateral inferior prefrontal cortex (LIPC) preferentially active during tasks that required semantic processing, but specific regions were also sensitive to task difficulty. Thus, it appears that frontal regions are involved both in the active retrieval from semantic memory and in processing specific semantic information.

Many researchers have suggested, however, that although frontal regions are involved in semantic retrieval, the storage of semantic information is primarily in the temporal regions (see Hodges et al., 1992). Indeed, another area that has been implicated in semantic processing is in the ventral region of the temporal lobes, centered on the fusiform gyrus, and especially in the left hemisphere. This area shows significant activation during word reading and object naming tasks, indicating it is not sensitive to the stimulus form but to the semantic content therein (see Martin, 2005, for a review). Furthermore, within this area, different subregions become more or less activated when subjects view faces, houses, and chairs (e.g., Chao et al., 1999), suggesting that different domains rely on different regions of neural tissue. This, of course, could be viewed as consistent with the category-specific deficits reviewed above. However, as noted by Martin and Chao (2001), although peak activation levels in response to objects from different domains reflect a certain degree of localization, the predominant finding is a pattern of broadly distributed activation throughout the ventral temporal and occipital regions, which is consistent with the idea that representations are distributed over large cortical regions.

Recently, Wheatley et al. (2005) reported data from a semantic priming study using fMRI that also converges on the notion of perceptual motor representations of meaning. Subjects silently read related, unrelated, or identical word pairs at a 250-ms SOA while being scanned. The related pairs consisted of category members that were not strongly associatively related (e.g., DOG-GOAT, but see the discussion above regarding the difficulty of selecting such items). Given the relatively fast SOA and that no overt response was required, Wheatley et al. argued that any evidence for priming should be a reflection of automatic processes. Consistent with other evidence that indicates there are reliable neural correlates of behavioral priming that were evidenced by reduced hemodynamic activity (Wiggs and Martin, 1998; Mummery et al., 1999; Rissman et al., 2003; Maccotta and Buckner, 2004), Wheatley et al. found decreased activity for identity pairs and a slightly smaller, but still significant, decrease for related pairs relative to the unrelated pairs condition. Importantly, Wheatley et al. were able to compare patterns of activation as a function of domain. Consistent with proposals by Barsalou (1999), they found that objects from animate objects yielded more activity in regions adjacent to sensory cortex, whereas manipulable artifacts resulted in greater activity in regions adjacent to motor cortex. These findings were taken as evidence that conceptual information about objects is stored, at least in part, in neural regions that are involved in perception and action.

Although the Wheatley et al. (2005) study used a task that was likely to minimize strategic processing, one question that remains to be addressed is whether the automatic and strategic processes involved in semantic priming tasks (see earlier discussion) can also be dissociated in neural tissue. In a recent study, Gold et al. (2006) reported that several of the brain regions previously implicated in processing during semantic tasks are differentially sensitive to the automatic and strategic processes involved in lexical decision tasks. In three experiments, Gold et al. manipulated prime target relatedness, SOA, and whether primes and targets were orthographically or semantically related. Long and short SOAs were intermixed in scanning runs to assess the relative contributions of strategic and automatic processes (see Neely, 1991). A comparison of orthographic and semantic priming conditions was included to determine whether any areas were particularly sensitive to the two sources of priming or whether priming effects are more general mechanisms. The results clearly indicated that different regions responded selectively to different conditions. Specifically, midfusiform gyrus was more sensitive to automatic than strategic priming, but only for semantically related primes, as this region did not show reduced activity for orthographic primes. Four regions were more sensitive to strategic than automatic priming, two in left anterior prefrontal cortex and bilateral anterior cingulate. Even more intriguing, the two regions in LIPC were further dissociated: The anterior region showed strategic semantic facilitation, as evidenced by decreased activity, relative to a neutral baseline, whereas the posterior region showed strategic semantic inhibition, or increased activity, relative to the neutral baseline. In addition, the medial temporal gyrus showed decreased activation concurrently with the anterior LIPC, supporting previous claims that these regions show greater activation in tasks that are more demanding of strategic processes but reduced activation when the strategic processes are less demanding (Wagner et al., 2000; Gold et al., 2005). In sum, it appears that the behavioral dissociations between automatic and strategic processes in priming tasks are also found in the neuroimaging data. The complexity of the patterns of activation involved in semantic tasks appears to indicate that the retrieval and storage of semantic information is indeed a distributed phenomenon that requires the coordination of a wide array of neural tissue.

## 2.28.10 Development and Bilingualism

Although we have attempted to provide a review of the major issues addressed in semantic memory research, there are clearly other important areas that we have not considered in detail because of length limitations. For example, there is a very rich area of developmental research addressing the acquisition of meaning in children (see Bloom, 2000, for a comprehensive review), along with work that attempts to capture the nature of semantic memory in older adulthood (see, e.g., Balota and Duchek, 1989). Of course, we touched upon these issues earlier when discussing how the small world networks of Steyvers and Tenenbaum (2005) develop over time, along with the work by Rosch (1975) on the development of categorization. Given that meaning is extracted from interactions with the environment, the developmental literature is particularly important to understand how additional years of experience mold the semantic system, especially in very early life. There are many interesting connections of this work to topics covered earlier in this chapter. For example, regarding the influence of preexisting structures on false memory, it is noteworthy that young children (5-year-olds) are more likely to produce phonological than semantic false memories, whereas older children (around 11 years and older) are more likely to produce the opposite pattern (see Dewhurst and Robinson, 2004). Possibly, this is a natural consequence of the development of a rich semantic network in early childhood that lags behind a more restricted phonological system.

Another very active area of research involves the nature of semantic representations in bilinguals (see Francis, 1999, 2005, for excellent reviews). For example, researchers have attempted to determine whether there is a common semantic substrate that is amodal, with each language having specific lexical level representations (e.g., phonology, orthography, syntax, etc.) that map onto this system. This contrasts with the view that each language engages distinct semantic level representations. Although there is still some controversy, the experimental results seem more consistent with the assumption that the semantic level is shared across languages, at least for skilled bilinguals. Evidence in support of this claim comes from a diverse range of tasks. For example, in a mixed language list, memory for the language of input is generally worse than memory for the concepts (e.g., Dalrymple-Alford and Aamiry, 1969). In addition, one finds robust semantic priming effects by translation equivalents (words in different languages with the same meaning, e.g., DOG in English and HUND in German), which is consistent with at least a partially shared semantic representation (e.g., de Groot and Nas, 1991; Gollan et al., 1997).

## 2.28.11 Closing Comments

The nature of how humans develop, represent, and efficiently retrieve information from their vast repository of knowledge has for centuries perplexed investigators of the mind. Although there is clearly considerable work to be done, recent advances in analyses of large-scale databases, new theoretical perspectives from embodied cognition and small world networks, and new technological developments allowing researchers to measure, *in vivo*, brain activity, are making considerable progress toward understanding this fundamental aspect of cognition.

## References


Albert R and Barabasi AL (2000) Topology of evolving networks: Local events and universality. *Phys. Rev. Lett.* 85: 5234–5237.

Anderson JR (2000) *Learning and Memory: An Integrated Approach*, 2nd edn. Pittsburgh: Carnegie Mellon.

Anderson JR and Bower GH (1973) *Human Associative Memory*. Washington DC: Hemisphere Press.

Anderson MC, Bjork RA, and Bjork EL (1994) Remembering can cause forgetting: Retrieval dynamics in long-term memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 1063–1087.

Arndt J and Hirshman E (1998) True and false recognition in MINERVA2: Explanations of a global matching perspective. *J. Mem. Lang.* 39: 371–391.

Atkinson RC and Juola JF (1974) Search and decision processes in recognition memory. In: Krantz DH, Atkinson RC, et al. (eds.) *Contemporary Developments in Mathematical Psychology: I Learning, Memory, and Thinking*, pp. 243–293. San Francisco: Freeman.

Baddeley A (2000) Short-term and working memory. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 77–92. Oxford: Oxford University Press.

Balota DA and Chumbley JI (1984) Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage. *J Exp. Psychol. Hum. Percept. Perform.* 10: 340–357.

Balota DA and Duchek JM (1989) Spreading activation in episodic memory: Further evidence for age-independence. *Q. J. Exp. Psychol.* 41A: 849–876.

Balota DA and Lorch RF (1986) Depth of automatic spreading activation: Mediated priming effects in pronunciation but not in lexical decision. *J. Exp. Psychol. Learn. Mem. Cogn.* 12: 336–345.

Balota DA and Paul ST (1996) Summation of activation: Evidence from multiple primes that converge and diverge within semantic memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 22: 827–845.

Balota DA, Cortese MJ, Sergent-Marshall S, Spieler DH, and Yap MJ (2004) Visual word recognition of single syllable words. *J. Exp. Psychol. Gen.* 133: 336–345.

Barsalou LW (1985) Ideals, central tendency, and frequency of instantiation as determinants of graded structure in categories. *J. Exp. Psychol. Learn. Mem. Cogn.* 11: 629–654.

Barsalou LW (1999) Perceptual symbol systems. *Behav. Brain Sci.* 22: 577–609.

Barsalou LW (2003) Abstraction in perceptual symbol systems. *Philos. Trans. R. Soc. Lond. Biol. Sci.* 358: 1177–1187.

Barsalou LW, Simmons WK, Barbey A, and Wilson CD (2003) Grounding conceptual knowledge in modality-specific systems. *Trends Cogn. Sci.* 7: 84–91.

Bartlett FC (1932) *Remembering*. Cambridge: Cambridge University Press.

Battig WF and Montague WE (1969) Category norms for verbal items in 56 categories: A replication and extension of the Connecticut category norms. *J. Exp. Psychol. Monogr.* 80: 1–46.

Bloom P (2000) *How Children Learn the Meanings of Words*. Cambridge MA: MIT Press.

Bousfield WA (1953) The occurrence of clustering in the recall of randomly arranged associates. *J. Gen. Psychol.* 49: 229–240.

Bruce D and Fagan RL (1970) More on the recognition and free recall of organized lists. *J. Exp. Psychol.* 85: 153–154.

Bruner JS, Goodnow JJ, and Austin GA (1956) *A Study of Thinking*. New York: Wiley.

Burgess C and Lund K (1997) Modeling parsing constraints with high-dimensional context space. *Lang. Cogn. Process.* 12: 177–210.

Capitani E, Laiacona M, Mahon B, and Caramazza A (2003) What are the facts of semantic category-specific deficits? A critical review of the clinical evidence. *Cogn. Neuropsychol.* 20: 213–261.

Caramazza A and Shelton JR (1998) Domain-specific knowledge systems in the brain: The animate-inanimate distinction. *J. Cogn. Neurosci.* 10: 1–34.

Carey S (1978) The child as a word learner. In: Halle M, Bresnan J, and Miller GA (eds.) *Linguistic Theory and Psychological Reality*, pp. 264–293. Cambridge MA: MIT Press.

Chao LL, Haxby JV, and Martin A (1999) Attribute-based neural substrates in temporal cortex for perceiving and knowing about objects. *Nat. Neurosci.* 2: 913–919.

Chwilla DJ and Kolk HHJ (2002) Three-step priming in lexical decision. *Mem. Cognit.* 30: 217–225.

Cofer CN, Bruce DR, and Reicher GM (1966) Clustering in free recall as a function of certain methodological variations. *J. Exp. Psychol.* 71: 858–866.

Collins AM and Loftus EF (1975) A spreading-activation theory of semantic processing. *Psychol. Rev.* 82: 407–428.

Collins A and Quillian MR (1969) Retrieval time from semantic memory. *J. Verb. Learn. Verb. Behav.* 8: 240–247.

Cree GS and McRae K (2003) Analyzing the factors underlying the structure and computation of the meaning of chipmunk, cherry, chisel, cheese and cello (and many other such concrete nouns). *J. Exp. Psychol. Gen.* 132: 163–201.

Cree GS, McRae K, and McNorgan C (1999) An attractor model of lexical conceptual processing: Simulating semantic priming. *Cogn. Sci.* 23: 371–414.

Crowder RG (1976) *Principles of Learning and Memory*. Hillsdale, NJ: Erlbaum.

Dalrymple-Alford EC and Aamiry A (1969) Word associations of bilinguals. *Psychon. Sci.* 21: 319–320.

Deese J (1959) On the prediction of occurrence of particular verbal intrusions in immediate free recall. *J. Exp. Psychol.* 58: 17–22.

de Groot AMB (1983) The range of automatic spreading activation in word priming. *J. Verb. Learn. Verb. Behav.* 22: 417–436.

de Groot AMB and Nas GLJ (1991) Lexical representation of cognates and non-cognates in compound bilinguals. *J. Mem. Lang.* 30: 90–123.

de Mornay Davies P (1998) Automatic semantic priming: The contribution of lexical- and semantic-level processes. *Eur. J. Cogn. Psychol.* 10: 398–412.

Dewhurst SA and Robinson CA (2004) False memories in children: Evidence for a shift from phonological to semantic associations. *Psychol. Sci.* 15: 782–786.

Durgunoglu AY and Neely JH (1987) On obtaining episodic priming in a lexical decision task following paired-associate learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 13: 206–222.

Ebbinghaus H (1885) *On Memory*. Ruger HA and Bussenius CE (trans.) New York: Teacher' College, 1913.

Faust ME, Balota DA, and Spieler DH (2001) Building episodic connections: Changes in episodic priming with age and dementia. *Neuropsychology* 15: 626–637.

Farah M and McClelland JL (1991) A computational model of semantic memory impairment: Modality-specificity and emergent category specificity. *J. Exp. Psychol. Gen.* 122: 339–357.

Fischler I (1977) Semantic facilitation without association in a lexical decision task. *Mem. Cognit.* 5: 335–339.

Fodor J (1983) *The Modularity of Mind*. Cambridge MA: MIT Press.

Francis WS (1999) Cognitive integration of language and memory in bilinguals: Semantic representation. *Psychol. Bull.* 125: 193–222.

Francis WS (2005) Bilingual semantic and conceptual representation. In: Kroll JF and de Groot AMB (eds.) *Handbook of Bilingualism: Psycholinguistic Approaches*, pp. 251–267. Oxford: Oxford University Press.

Gelman SA and Markman EM (1986) Categories and induction in young children. *Cognition* 23: 183–208.

Gibson JJ (1979) *The Ecological Approach to Visual Perception*. Hillsdale, NJ: Erlbaum.

Glenberg AM and Kaschak MP (2002) Grounding language in action. *Psychon. Bull. Rev.* 9: 558–565.

Glenberg AM and Robertson DA (2000) Symbol grounding and meaning: A comparison of high-dimensional and embodied theories of meaning. *J. Mem. Lang.* 43: 379–401.

Gold BT, Balota DA, Cortese MJ, et al. (2005) Differing neuropsychological and neuroanatomical correlates of abnormal reading in early-stage semantic dementia and dementia of the Alzheimer type. *Neuropsychologia* 43: 833–846.

Gold BT, Balota DA, Jones SJ, Powell DK, Smith CD, and Andersen AH (2006) Dissociation of automatic and strategic lexical-semantics: fMRI evidence for differing roles of multiple frontotemporal regions. *J. Neurosci.* 26: 6523–6532.

Gollan TH, Forster KI, and Frost R (1997) Translation priming with different scripts: Masked priming with cognates and noncognates in Hebrew-English bilinguals. *J. Exp. Psychol. Learn. Mem. Cogn.* 23: 1122–1139.

Hart J, Berndt RS, and Caramazza A (1985) Category-specific naming deficit following cerebral infarction. *Nature* 316: 439–440.

Herrnstein RJ, Loveland DH, and Cable C (1976) Natural concepts in pigeons. *J. Exp. Psychol. Anim. Behav. Process.* 2: 285–302.

Hines D, Czerwinski M, Sawyer PK, and Dwyer M (1986) Automatic semantic priming: Effect of category exemplar level and word association level. *J. Exp. Psychol. Hum. Percept. Perform.* 12: 370–379.

Hintzman DL (1986) ''Schema abstraction'' in a multiple trace memory model. *Psychol. Rev.* 93: 411–428.

Hintzman DL (1988) Judgements of frequency and recognition memory in a multiple-trace memory model. *Psychol. Rev.* 95: 528–551.
Hodges JR, Patterson K, Oxbury S, and Funnell E (1992) Semantic dementia: Progressive fluent aphasia with temporal lobe atrophy. *Brain* 115: 1793–1806.
Hoffman AB and Murphy GL (2006) Category dimensionality and feature knowledge: When more features are learned as easily as fewer. *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 301–315.
Hoffman RR, Bringmann W, Bamberg M, and Klein R (1987) Some historical observations on Ebbinghaus. In: Gorfein D and Hoffman R (eds.) *Memory and Learning: The Ebbinghaus Centennial Conference*, pp. 57–76. Hillsdale, NJ: Erlbaum.
Howard D and Patterson K (1992) *The Pyramids and Palm Trees Test*. Bury St. Edmunds: Thames Valley Test Company.
Hutchison KA (2003) Is semantic priming due to association strength or feature overlap? A micro-analytic review. *Psychon. Bull. Rev.* 10: 785–813.
Hutchison KA and Balota DA (2005) Decoupling semantic and associative information in false memories: Explorations with semantically ambiguous and unambiguous critical lures. *J. Mem. Lang.* 52: 1–28.
Jacoby LL (1991) A process dissociation framework: Separating automatic from intentional uses of memory. *J. Mem. Lang.* 30: 513–541.
Jeong H, Kahng B, Lee S, Kwak CY, Barabasi AL, and Furdyna JK (2000) Monte Carlo simulation of sinusoidally modulated superlattice growth. *Phys. Rev. E Stat. Nonlin. Soft Matter Phys.* 65: 031602–031605.
LaBerge D and Samuels SJ (1974) Toward a theory of automatic information processing in reading. *Cogn. Psychol.* 6: 293–323.
Landauer TK and Dumais ST (1997) A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction, and representation of knowledge. *Psychol. Rev.* 104: 211–240.
Leach E (1964) Anthropological aspects of language: Animal categories and verbal abuse. In: Lenneberg EH (ed.) *New Directions in the Study of Language.* Cambridge, MA: MIT Press.
Livesay K and Burgess C (1998) Mediated priming in high-dimensional semantic space: No effect of direct semantic relationships or co-occurrence. *Brain Cogn.* 37: 102–105.
Logothetis NK and Wandell BA (2004) Interpreting the BOLD signal. *Annu. Rev. Physiol.* 66: 735–769.
Lucas M (2000) Semantic priming without association: A meta-analytic review. *Psychon. Bull. Rev.* 7: 618–630.
Lupker SJ (1984) Semantic priming without association: A second look. *J. Verb. Learn. Verb. Behav.* 23: 709–733.
Maccotta L and Buckner RL (2004) Evidence for neural effects of repetition that directly correlate with behavioral priming. *J. Cogn. Neurosci.* 16: 1625–1632.
MacKay DG, Burke DM, and Stewart R (1998) HM's language production deficits: Implications for relationships between memory, semantic binding, and the hippocampal system. *J. Mem. Lang.* 38: 28–69.
Martin A (2005) Functional neuroimaging of semantic memory. In: Cabeza R and Kingstone A (eds.) *Handbook of Functional Neuroimaging of Cognition*, pp. 153–186. Cambridge, MA: MIT Press.
Martin A and Chao LL (2001) Semantic memory and the brain: Structure and processes. *Curr. Opin. Neurobiol. Cogn. Neurosci.* 11: 194–201.
Martin A, Haxby JV, Lalonde FM, Wiggs CL, and Ungerleider LG (1995) Discrete cortical regions associated with knowledge of color and knowledge of action. *Science* 270: 102–105.
McCloskey M and Glucksberg S (1979) Decision processes in verifying category membership statements: Implications for models of semantic memory. *Cogn. Psychol.* 11: 1–37.
McKoon G and Ratcliff R (1979) Priming in episodic and semantic memory. *J. Verb. Learn. Verb. Behav.* 18: 463–480.
McKoon G and Ratcliff R (1992) Spreading activation versus compound cue accounts of priming: Mediated priming revisited. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 1155–1172.
McKoon G, Ratcliff R, and Dell GS (1986) A critical evaluation of the semantic episodic distinction. *J. Exp. Psychol. Learn. Memo. Cogn.* 12: 295–306.
McNamara TP and Altarriba J (1988) Depth of spreading activation revisited: Semantic mediated priming occurs in lexical decisions. *J. Mem. Lang.* 27: 545–559.
McRae K (2004) Semantic memory: Some insights from feature-based connectionist attractor networks. In: Ross BH (ed.) *Psychology of Learning and Motivation*, vol. 45, pp. 41–86. San Diego: Elsevier.
McRae K, De Sa VR, and Seidenberg MS (1997) On the nature and scope of featural representations of word meaning. *J. Exp. Psychol. Gen.* 126: 99–130.
McRae K, Cree GS, Westmacott R, and de Sa VR (1999) Further evidence for feature correlations in semantic memory. *Can. J. Exp. Psychol.* (Special issue on models of word recognition) 53: 360–373.
McRae K, Cree GS, Seidenberg MS, and McNorgan C (2005) Semantic feature production norms for a large set of living and nonliving things. *Behav. Res. Methods Instr. Comput.* 37: 547–559.
Medin DL (1989) Concepts and conceptual structure. *Am. Psychol.* 44: 1469–1481.
Meyer DE and Schvaneveldt RW (1971) Facilitation in recognizing words: Evidence of a dependence upon retrieval operations. *J. Exp. Psychol.* 90: 227–234.
Milgram S (1967) The small world problem. *Psychol. Today* 2: 60–67.
Miller GA (1990) WordNet: An on-line lexical database. *Int. J. Lexiogr.* 3: 235–312.
Mummery CJ, Shallice T, and Price CJ (1999) Dual-process model in semantic priming: A functional neuroimaging perspective. *Neuroimage* 9: 516–525.
Murphy G (2002) *The Big Book of Concepts*. Cambridge, MA: MIT Press.
Neely JH (1977) Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *J. Exp. Psychol. Gen.* 106: 226–254.
Neely JH (1991) Semantic priming effects in visual word recognition: A selective review of current findings and theories. In: Besner D and Humphreys G (eds.) *Basic Processes in Reading: Visual Word Recognition*, pp. 236–264. Hillsdale, NJ: Erlbaum.
Neely JH and Durgunoglu AY (1985) Dissociative episodic and semantic priming effects in episodic recognition and lexical decision tasks. *J. Mem. Lang.* 24: 466–489.
Nelson DL, McEvoy CL, and Schreiber TA (1998) The University of South Florida word association, rhyme, and word fragment norms. http://www.usf.edu/FreeAssociation/.
Osgood CE, Suci GJ, and Tanenbaum PH (1957) *The Measurement of Meaning*. Urbana: University of Illinois Press.
Pecher D and Raaijmakers JGW (1999) Automatic priming effects for new associations in lexical decision and perceptual identification. *Q. J. Exp. Psychol.* 52A: 593–614.
Pecher D, Zeelenberg R, and Barsalou LW (2003) Verifying properties from different modalities for concepts produces switching costs. *Psychol. Sci.* 14: 119–124.
Pecher D, Zeelenberg R, and Barsalou LW (2004) Sensorimotor simulations underlie conceptual representations: Modality-specific effects of prior activation. *Psychon. Bull. Rev.* 11: 164–167.

Petersen SE, Fox PT, Posner M, Mintun M, and Raichle M (1988) Positron emission topographic studies of the cortical anatomy of single word processing. *Nature* 331: 585–589.
Pexman PM, Lupker SJ, and Hino Y (2002) The impact of feedback semantics in visual word recognition: Number of features effects in lexical decision and naming tasks. *Psychon. Bull. Rev.* 9: 542–549.
Pexman PM, Holyk GG, and Monfils M-H (2003) Number of features effects and semantic processing. *Mem. Cognit.* 31: 842–855.
Pinker S (1994) *The Language Instinct*. New York: Harper Collins.
Posner MI and Keele SW (1968) On the genesis of abstract ideas. *J. Exp. Psychol.* 77: 353–363.
Posner MI and Snyder CRR (1975) Attention and cognitive control. In: Solso R (ed.) *Information Processing and Cognition: The Loyola Symposium*, pp. 55–85. Hillsdale, NJ: Erlbaum.
Quillian M (1968) Semantic memory. In: Minsky M (ed.) *Semantic Information Processing*, pp. 227–270. Cambridge, MA: MIT Press.
Quine WVO (1960) *Word and Object*. Cambridge, MA: MIT Press.
Riddoch MJ and Humphreys GW (1987) Visual object processing in optic aphasia: A case of semantic access agnosia. *Cogn. Neuropsychol.* 4: 131–185.
Rissman J, Eliassen JC, and Blumstein SE (2003) An event-related fMRI investigation of implicit semantic priming. *J. Cogn. Neurosci.* 15: 1160–1175.
Roediger HL III and McDermott KB (1995) Creating false memories: Remembering words not presented in lists. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 803–814.
Roediger HL III, Balota DA, and Watson JM (2001a) Spreading activation and arousal of false memories. In: Roediger HL and Nairne JS (eds) *The Nature of Remembering: Essays in Honor of Robert G. Crowder*, pp. 95–115. Washington DC: American Psychological Association.
Roediger HL III, Watson JM, McDermott KB, and Gallo DA (2001b) Factors that determine false recall: A multiple regression analysis. *Psychon. Bull. Rev.* 8: 385–407.
Rogers TT, Lambon RMA, Garrard P, et al. (2004) Structure and deterioration of semantic memory: A neuropsychological and computational investigation. *Psychol. Rev.* 111: 205–235.
Roget PM (1911) *Roget's Thesaurus of English Words and Phrases*. Available from Project Gutenberg Illinois Benedictine College, Lisle, IL.
Rosch E (1973) On the internal structure of perceptual and semantic categories. In: Moore TE (ed.) *Cognitive Development and the Acquisition of Language*, pp. 111–144. New York: Academic Press.
Rosch E (1975) Cognitive representations of semantic categories. *J. Exp. Psychol. Gen.* 104: 192–233.
Rosch E, Mervis CB, Gray WD, Johnson DM, and Boyes-Braem P (1976) Basic objects in natural categories. *Cogn. Psychol.* 8: 382–440.
Roskies AL, Fiez JA, Balota DA, and Petersen SE (2001) Task-dependent modulation of regions in left inferior frontal cortex during semantic processing. *J. Cogn. Neurosci.* 13: 1–16.
Sachett C and Humphreys GW (1992) Calling a squirrel a squirrel but a canoe a wigwam: A category-specific deficit for artefactual objects and body parts. *Cogn. Neuropsychol.* 9: 73–86.
Sayette MA, Hufford MR, and Thorson GM (1996) Developing a brief measure of semantic priming. *J. Clin. Exp. Neuropsychol.* 8: 678–684.
Scoville WB and Milner B (1957) Loss of recent memory after bilateral hippocampal lesions. *J. Neurol. Neurosurg. Neuropsychiatry* 20: 11–21.
Simons JS, Graham KS, and Hodges JR (2002) Perceptual and semantic contributions to episodic memory: Evidence from semantic dementia and Alzheimer's disease. *J. Mem. Lang.* 47: 197–213.
Smith EE, Shoben EJ, and Rips LJ (1974) Structure and process in semantic memory: A featural model for semantic decisions. *Psychol. Rev.* 81: 214–241.
Solomon KO and Barsalou LW (2004) Perceptual simulation in property verification. *Mem. Cognit.* 32: 244–259.
Sperling G (1960) The information available in brief visual presentation. Psychol. Monogr. 74(11) (Whole No. 498).
Spieler DH and Balota DA (1996) Characteristics of associative learning in younger and older adults: Evidence from an episodic priming paradigm. *Psychol. Aging* 11: 607–620.
Steyvers M and Tenenbaum JB (2005) The large-scale structure of semantic networks: Statistical analyses and a model of semantic growth. *Cogn. Sci.* 29: 41–78.
Thompson-Schill SL, Kurtz KJ, and Gabrieli JDE (1998) Effects of semantic and associative relatedness on automatic priming. *J. Mem. Lang.* 38: 440–458.
Tulving E (1972) Episodic and semantic memory. In: Tulving E and Donaldson W (eds.) *Organization of Memory*, pp. 381–403. New York: Academic Press.
Tulving E (1985) Memory and consciousness. *Can. Psychol.* 26: 1–12.
Tulving E and Pearlstone Z (1966) Availability versus accessibility of information in memory for words. *J. Verb. Learn. Verb. Behav.* 5: 381–391.
Wagner AD, Koutstaal W, Maril A, Schacter DL, and Buckner RL (2000) Task-specific repetition priming in left inferior prefrontal cortex. *Cereb. Cortex* 10: 1176–1184.
Warrington EK and McCarthy R (1987) Categories of knowledge: Further fractionations and an attempted integration. *Brain* 110: 1273–1296.
Watts DJ and Strogatz SH (1998) Collective dynamics of "small-world" networks. *Nature* 393: 440–442.
Wheatley T, Weisberg J, Beauchamp MS, and Martin A (2005) Automatic priming of semantically related words reduces activity in the fusiform gyrus. *J. Cogn. Neurosci.* 17: 1871–1885.
Wickens DD (1973) Some characteristics of word encoding. *Mem. Cogn.* 1: 485–490.
Wiggs CL and Martin A (1998) Properties and mechanisms of perceptual priming. *Curr. Opin. Neurobiol.* 8: 227–233.
Wilson M (2002) Six views of embodied cognition. *Psychon. Bull. Rev.* 9: 625–636.

# 2.29 Concept and Category Learning in Humans

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## 2.29.1 Introduction

Concepts and categories are crucial for intelligent thought and action. A child needs to learn to tell toys from tools and which types of dogs can be petted. A student needs to learn to distinguish the principle underlying a math problem, so that relevant principle knowledge can be applied. Researchers need to be able to decide what type of person has asked them to collaborate, to understand the concept of confounding, and to be able to communicate new ideas to others. The focus of this chapter is understanding the learning of categories and concepts. This learning is critical not only because little of this knowledge is innate but also because the learning of concepts and categories is a large part of acquiring knowledge.

We use concept to refer to a mental representation, an idea, that picks out a class of entities. A category is the class or set of entities that is referred to by the concept. One has a concept of dog, and then there is the category of dogs (both real and imagined). Different things in the category can all be treated similarly, with respect to some purpose. Cars are members of a category because they have much in common in terms of appearance and use. However, one might want to make finer distinctions, such as separating cars that can carry much stuff for moving from sports cars; at other times, such as in compiling assets, one might want to think of an expensive sports car as part of the same class as a boat and house. When possible, we use categories to refer to the learning or use of the members and concepts to refer to the knowledge of categories. Despite this distinction, they are often used interchangeably because it is often true that one is dealing with both together.

We also need to address briefly two important issues: Origins and types. First, although some researchers argue for the independent existence of concepts in the world (separate from the organisms that perceive them), we, as psychologists, believe it is more useful to think of them as arising jointly from the fit between the world and the organism. Although it is true that we do not just have any concepts, it is also true that different organisms have different concepts, and even among humans, the concepts we have often are a function of human activity. Second, although much of the work has focused on object categories, we clearly have many other categories besides objects, people, situations, problems, scenes, and so on. We try to include a variety of types in our discussion (also see Medin et al., 2000).

In this chapter, we provide an overview of the work on concept and category learning, with a focus on experimental work and modeling. We begin by considering the functions of concepts. We then address a large body of research that has examined conceptual structure for classification, with particular emphasis on prototype and exemplar approaches and models. We argue that this work has missed some important aspects of both how categories are learned and the importance of structure and prior knowledge. A goal of this chapter is to integrate the work on concepts and categories into the areas of cognition in which they are so crucial. All cognitive activity relies on concepts in some way, so an understanding of how they are learned is likely to have an impact on much other research. We provide an integration in three ways. One, we examine the learning of concepts and categories from a goal-oriented view, asking how the ways in which they might be learned influence the representation available for other cognitive activities. Two, we consider more complex concepts, as would be needed to account for results in most areas in which concepts are used. Three, we address this integration more directly by considering two very different areas of cognition, problem solving and language.

### 2.29.1.1 Functions of Concepts and Categories

Concepts and categories are fundamental building blocks of cognition. Murphy (2002) calls them the mental glue in that they link our past experiences (with toys, dogs, mathematical problems, collaborators) to our current ones. They are a part of all cognitive, and many noncognitive, theories. We mention here a few functions.

#### *2.29.1.1.1 Classification*

Classification is the determination that something is a member of a particular category: A carrot, an extrovert, a permutations problem, an instance of insurgency. This action allows one to access knowledge about the category that can be used for a variety of other functions.

#### *2.29.1.1.2 Prediction and inference*

When an object is classified as a carrot, you can predict how it will taste, how crunchy it will be. You can use knowledge of the category to infer how it was grown and how similar it is to a beet. Prediction is often considered a key function of categories (e.g., Anderson, 1991) in that it allows for selection of plans and actions.

#### *2.29.1.1.3 Understanding and explanation*

People need to know not just what, but why. We can explain aberrant behavior if we know that the person was grieving or drunk. This characterization might change our future actions with the person. If we start watching a TV program part-way through and cannot understand what is happening, being told it involves a love triangle may help us to make sense of the events.

#### 2.29.1.1.4 Communication

We are social animals, and much of our activity is geared toward interacting with others. Concepts provide a kind of social glue as well, as they facilitate communication and allow us to learn new concepts by indirect experience.

Concepts and categories underlie much of mental life, and their learning is complex. We must learn not just to classify items: Knowing something is a carrot, a permutations problem, or an extrovert does not help unless we know enough about carrots, permutations, or extroverts to accomplish our goals (e.g., how to prepare the carrot, solve the problem, quiet the extrovert). Thus, as we learn to tell what category an item is in, we also have to learn much else about the concept to allow prediction, explanation, and communication. The corresponding distinction between knowledge that allows one to classify and knowledge that allows one to perform other conceptual functions is a central one for this chapter, as well as for understanding concepts and categories in other areas of cognition.

## 2.29.2 Conceptual Structure

We turn now to the structure of concepts. How are categories mentally represented to allow these various functions to be accomplished? This question is essential for any examination of concept and category learning, because it provides a clear target for what must be learned. We can only provide a brief overview, but fuller descriptions can be read in Medin (1989) and Murphy (2002).

### 2.29.2.1 Views and Models

What determines which items go together in a category and which items are in different categories? A common intuition is that it depends upon similarity – more similar items are in the same category. One can think of items as consisting of a set of features. Similarity is defined as the overlap of features (such as Tversky, 1977) or, if one prefers spatial metaphors, as closeness in some multidimensional space (e.g., Shepard, 1962a,b). This idea of similarity underlies many views of conceptual structure, three of which are summarized in **Table 1**. We briefly present these views and associated formal models with a focus on classification learning.

#### 2.29.2.1.1 Classical view

The classical view of concepts takes a strict view of similarity: All items in a category must have a specific set of features. If an item has those features, it is in the category; if it does not, it is not. One can think of this as a definitional view of categories: The features are singly necessary and jointly sufficient for category membership. A triangle is any closed two-dimensional figure that has three straight sides. Any item that has all of those features is a triangle, and any item that does not have all of those features is not a triangle. In addition, the view includes the rule-based idea, in which items are classified as being in a category if they meet some rule, such as red, or red and large (e.g., Bruner et al., 1956). This view has a long history (see Murphy, 2002), and it matches many intuitions about category members sharing some common characteristics. However, because the classical view assumes all members possess the same set of common features, it does not explain why some category members are more typical than others (e.g., robins vs. penguins) or why it has proven so difficult for people to come up with a set of defining features for most categories (Wittgenstein, 1953, has a famous example of trying to define the category games). There are no current formal models that rely solely on a classical view.

#### 2.29.2.1.2 Prototype view

The prototype view (or probabilistic view) keeps the attractive assumption that there is some underlying common set of features for category members but relaxes the requirement that every member have all the features. Instead, it assumes there is a probabilistic matching process: Members of the category have more features, perhaps weighted by importance, in common with the prototype of this category than with

**Table 1** Similarity-based views of conceptual structure and their classification decisions

| | | |
|---|---|---|
| Classical | Unitary description: Definitional, rule-based | Classification: Category member if and only if all features are true of an item |
| Prototype | Unitary description (prototype): Probabilistic | Classification: Category member if more (weighted) features are true of the prototype than of other prototypes |
| Exemplar | No unitary description: Disjunctive representation | Classification: Category member if more similar to (weighted) category members than to members of other categories |

prototypes of other categories (and perhaps some minimum match level is required). An early presentation is available in Rosch and Mervis (1975), with a more recent presentation in Hampton (2006).

This type of representation has major implications for how to think about categories. First, some members may have more of the prototype features than others, such as a robin having more bird prototype features than a penguin. People tend to judge robins as better examples of birds than are penguins and are faster to classify robins as birds than they are to classify penguins as birds. Second, this view suggests that the category boundaries, which were strict in the classical view, may be fuzzy, with some cases that are far from the prototype and maybe even almost as close to another prototype. For example, whales have many fish-like properties, and bats have many bird-like properties. Both are viewed as poor examples of the mammal category and are slow to be verified as members of that category. Overall, this view leads to a set of category members that tend to have a family resemblance – no defining features, but some features will be possessed by many members and some features by a few members (similar to an extended family). Rosch and Mervis (1975) argue that this type of family resemblance characterizes many natural categories. See the top half of **Figure 1** for a simple example.

Smith and Minda (1998, 2000; Minda and Smith, 2001) proposed a model of prototype-based classification that matches an item to the various prototype representations and picks the most similar (see also Hampton, 1993). Using the spatial distance idea of similarity, the prototype models (a) determine the distance from the test item to each prototype, (b) compute the similarity from the distance, and (c) choose the category prototype as a function of the similarity. There are several specific choices to make as to how

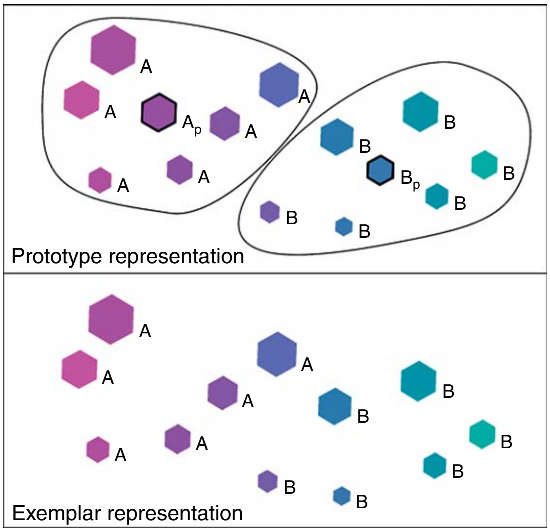


**Figure 1** Sample prototype and exemplar representations. Members of Category A tend to be large and pink, whereas members of Category B tend to be small and turquoise. The prototype representation in the top panel also includes a prototype item with the bold outline and P subscript, which was not presented but represents the center of the presented items. (Although the prototypes here can be characterized as instances, more generally prototypes are summary representations.) The exemplar representations in the bottom panel include all individual category members, but do not group them or include a center.

to formalize these ideas. For the reader interested in formal models, we provide a simple one with additive similarity and just two categories in **Table 2**.

The learning of the category is the building of this summary representation. Exactly how the prototype is learned is not usually specified. One possibility, for simple cases, is to assume a simple associationist-like mechanism, with frequently occurring values being more reinforced. The point is that the earlier experiences are used to build the summary representation,

**Table 2** Sample prototype model calculations (assuming *N* dimensions, city-block[a] metric, and two categories, A and B)

| *To calculate* | *Formula* | *Comment* |
|---|---|---|
| (a) Distance of test item, *t*, to prototype, *P* | $d_{tP} = \sum_{k=1}^{N} w_k \lvert t_k - P_k \rvert$ | $w_k$ Weights each dimension *k* by attention (or importance)[b] |
| (b) Similarity of test item, *t*, to prototype, *P* | $S_{tP} = 1 - d_{tP}$ | Additive similarity [c] |
| (c) Probability of choosing Category *A* | $P(A \mid t) = \dfrac{S_{tP,A}}{S_{tP,A} + S_{tP,B}}$ | Luce Choice rule over prototypes' similarities to the test item |

[a]City-block metric is common when the dimensions' distances seem to be evaluated separately and then added. It is as if one is walking in a city and can turn only at the corners, rather than as the crow flies (Euclidean). It is used here as an illustration of one distance metric.
[b]The difference between the values of the test item and prototype on each dimension is summed, weighted by the attention given to that dimension. The sum of the weights is constrained to be equal to 1 ($\Sigma$ $w_k = 1$) as a limited-capacity system (total amount of attention is limited).
[c]Similarity is assumed to be a linearly decreasing function of psychological distance.

which is then slightly revised with new experiences (in the same way one can keep various statistics of a sample as each new item is added).

#### 2.29.2.1.3 Exemplar view

The idea of a summary representation is attractive, and we clearly know a lot about categories such as birds. However, an alternative view is that the knowledge we use in making category judgments such as classification is not this summary representation but the set of category members: The conceptual structure is a collection of the mental representations of category members. When an item is presented, the person matches the representation of the item to the various previous items' representations and uses some subset (perhaps even just one item) selected by their similarity to the current item's representation. Thus, to classify a hawk as a bird, one would retrieve some earlier representations of hawks or similar birds and note their bird category; to decide what it ate, one would again use these more specific representations.

We know this lack of a summary representation seems strange at first thought, but often a new item will remind one of some old item from which one can make a classification or prediction ("is this person like my friend Bill in other ways?"). The exemplar view is an extension of this idea to allow the use of specific instances to classify the current item. Imagine you see a new ostrich-like animal with some unusual bird characteristics. If you relied on the bird prototype, you might not classify it as a bird. However, if you used similar birds, then you would likely classify it as a bird, as well as predict it probably does not fly or eat worms.

This exemplar view accounts for the prototype-like effects mentioned earlier. Some category members, such as robins, will be viewed as more typical than others, such as penguins, because a robin will be similar to many birds (not just the large number of robins, but also sparrows, thrushes, etc.), whereas a penguin will be similar mainly to the few penguins one has seen. The uncertain cases will be exemplars that are not very similar to any items in a category and may even be a little bit similar to atypical items in another category (see **Figure 1**, lower panel).

There are a number of formal exemplar models, with the best known being the Context Model (Medin and Schaffer, 1978), which was extended in a number of ways by the Generalized Context Model (GCM, Nosofsky, 1986). Like the prototype model, exemplar models also use the similarity of the test item to each category, but because there is no summary representation, the similarity of the test item to the category is just the sum of the similarity of the test item to each of the items in the category. The other main difference from prototype models is that multiplicative, rather than additive, similarity is assumed. Multiplicative similarity means that the similarity is not a linear function of the psychological distance, but instead, very close items (ones that are similar to the test item on many dimensions) matter much more. More specifically, exemplar models (a′) compare the similarity of the test item to all items, (b′) compute the similarity of the test item to each category by summing the test item's similarity to each of the category members, and then (c′) choose the category as a function of similarity. The equations for one such model are presented in **Table 3** for those readers with an interest in formal models. Most exemplar models capture only classification performance, but ALCOVE (Kruschke, 1992) extends the GCM to allow some

**Table 3** Sample exemplar model calculations (assuming *N* dimensions, city-block[a] metric, and two categories, A and B)

| *To calculate* | *Formula* | *Comment* |
|---|---|---|
| (a′) Distance of test item, *t*, to exemplar, $X_j$ | $d_{tj} = \sum_{k=1}^{N} w_k \lvert t_k - X_{jk} \rvert$ | $w_k$ Weights each dimension *k* by attention (or importance)[b] |
| (b′) Similarity of test item, *t*, to exemplar, $X_j$ | $S_{tj} = \exp(-c \cdot d_{tj})$ | Multiplicative similarity,[c] c indicates sharpness of generalizations |
| (c′) Probability of choosing Category *A* | $P(A \mid t) = \dfrac{\sum_{i \in A} S_{ti}}{\sum_{i \in A} S_{ti} + \sum_{i \in B} S_{ti}}$ | Luce Choice rule over exemplars' similarities to the test item |

[a]City-block metric is common when the dimensions' distances seem to be evaluated separately and then added. It is as if one is walking in a city and can turn only at the corners, rather than as the crow flies (Euclidean). It is used here just as an illustration of one distance metric.
[b]The difference between the values of the test item and prototype on each dimension is summed, weighted by the attention given to that dimension. The sum of the weights is constrained to be equal to 1 ($\Sigma\, w_k = 1$) as a limited-capacity system (total amount of attention is limited).
[c]Multiplicative similarity is not a linear function of psychological distance. Rather, close items (small distance) have much greater effect than in a linear function. The exponential function is commonly used and has a quick drop-off with distance. (Note that the exponential of the sum of distances across each dimension is equal to multiplying the exponential of each dimensional distance, since $\exp[a+b] = \exp[a] \cdot \exp[b]$.)

learning. In addition, there is no learning of summary representations, because only individual items need to be stored.

### 2.29.2.2 Evaluations of Prototype and Exemplar Models

There have been many (many) comparisons of prototype and exemplar models (for a review, see Murphy, 2002). The general result is that exemplar models do as well or better than prototype models in most cases (though see Smith and Minda, 1998, 2001). Our view, summarizing over many results, is that the advantage is largely a result of two factors: similarity calculation and selectivity (Ross and Makin, 1999). First, the exemplar models' multiplicative similarity (compared to the prototype models' usual assumption of additive similarity) means that the model does not combine features independently but, rather, is sensitive to the relational information among the features (e.g., Medin and Schaffer, 1978). The combination of features is being used beyond their separate contribution to determining classification. Thus, if one encountered small birds that sang and large birds that squawked, a prototype representation would not be sensitive to that particular relational (cooccurrence) information, whereas an exemplar model would. Although it is not a usual assumption, prototype models might also incorporate multiplicative similarity (e.g., Smith and Minda, 1998); this helps the fit, but it does not mimic the predictions of the exemplar model. (Multiplicative similarity is a nonlinear function, so calculating multiplicative similarity on the mean (prototype) is not the same as the mean of multiplicative similarities on the individual instances.) In fact, exemplar models implicitly keep all the statistical information (e.g., frequency, variability, cooccurrence) by keeping all the exemplars. One might argue that a prototype model could also keep various statistical information around to make it equivalent to such exemplar models (e.g., Barsalou, 1990), but no one has proposed such a formal model. Second, because exemplar models have no summary representation, the same knowledge is not used for all the different decisions. Thus, even unusual items can be classified by similarity to earlier unusual similar members. The ability to use different knowledge for different decisions means that the exemplar model can classify unusual items without compromising its ability to easily classify more typical items. This flexibility is important in allowing the exemplar model to fit a variety of classification data.

The exemplar model fits the data well for many classification experiments but has difficulties with other aspects of category-related judgments. One major issue is that it has no place for these summary representations that we all find attractive in thinking about concepts. In particular, to answer the question as to why these items are all members of the same category, the exemplar view is left with the unsatisfying answer that "they all have the same category label." That may be fine for arbitrary experimenter-defined categories in the laboratory but seems woefully inadequate for permutation problems, extroverts, and love triangles. (Note that the classical view can point to a definition and the prototype view to similarity to some common summary representation.)

### 2.29.2.3 Combined Models

It seems likely that people are not restricted to a single means of representation and that we might combine advantages of prototype and exemplar models, or at least general and more specific knowledge. We consider two types of proposals. First, one could take a prototype model and an exemplar model and simply combine them with some means of determining whether a decision would be based on the prototypes or exemplars. Smith and Minda (1998) show that a combined model can provide a better account of the data, with the prototype being more influential earlier, when each item to be classified has been presented only a few times, and the exemplar model controlling responses more as the same items are presented often. They do not specify a control mechanism, but perhaps the model that has greater confidence in its choice might determine the classification.

Second, there have been models that build upon simple models with a more integrated approach. Interestingly, rules, which can be viewed as simple classical models, are making a comeback: They appear to work better as part of the answer rather than the sole answer. ATRIUM (Erickson and Kruschke, 1998) combines simple rules with an exemplar model, ALCOVE (Kruschke, 1992). The authors provide experimental evidence showing that both types of knowledge can influence a task and then address how the two types of knowledge might be integrated to provide an account of the data. All inputs are examined by both the rule and exemplar modules, with the response a weighted function determined by how much attention is given to each. The model learns to shift attention between the modules as a function of which module is better at classifying particular inputs. (Also see the RULEX model by Nosofsky et al., 1994.)

A very different combined model, COVIS, has been proposed by Ashby and colleagues (Ashby and Ennis, 2006, present an overview). Human category learning is assumed to be mediated by a number of functionally distinct neurobiological systems, and the goal is to elucidate these systems and their behavioral consequences. An explicit system is important for rule-based tasks – those tasks with a focus on a single dimension for which people might generate and test hypotheses. Another, procedural-based, system deals with information-integration tasks that require combining information from multiple dimensions. This model combines rule- and procedural-based knowledge to account for a variety of behavioral results and data from neuropsychological patients.

### 2.29.2.4 Evaluation of Work on Conceptual Structure

#### *2.29.2.4.1 Successes*

The separation of different views of conceptual structure has generated much research. The prototype view has greatly extended our understanding of natural categories. The formal modeling on the exemplar approach has shown that exemplar representations coupled with multiplicative similarity are able to account for a wide variety of classification results. The more recent prototype modeling work shows that some findings that seemed problematic for prototype models may not be, though the exemplar model still seems to have an edge on overall accounts of the results. Although almost all of the exemplar work has focused on learning artificial categories, some recent work suggests the exemplar models may fit some real-world categories as well (reviewed in Storms, 2004).

#### *2.29.2.4.2 Limitations*

We label this part of the evaluation 'limitations' because the difficulties are not failures but restrictions. The simple point, to be elaborated in the next section, is that the field has examined only a small part of the picture for conceptual structure and learning. Thus, although the prototype and exemplar approaches and models have been explored extensively, especially in the laboratory, our understanding of concept and category learning may be quite limited.

First, almost all the work on adult category learning until a decade ago focused on classification learning, how people learn to assign items to specified categories. We learn concepts and categories in many ways – such as by interactions, inferences, problem solving, instruction – yet these have received little attention in research on category learning. Not only is much of the laboratory work limited to classification learning, it has rarely varied from a small range of particulars (here is an incomplete list): two categories, small number of features, small number of values per feature, small number of items per category, and divorced from any prior knowledge. Given all the possible ways that even the classification paradigm might be done, these seem very limiting. Of course, it is possible that all the ways of learning and all the possible ways of changing the classification paradigm will not matter in terms of our understanding of category learning, but the evidence suggests just the opposite. As elaborated in the next section, it appears that many of these changes lead to important differences in what is learned.

Second, the items being learned have been limited. In addition to the ways mentioned, almost all have been objects (or descriptions of objects), with little examination of problems, people, situations, scenes, and so on. In addition, the items in most experiments have generally consisted of features only, with no relational structure beyond cooccurrences. None of the main classification theories developed in the exemplar-prototype debates allow relations in their item representations. Given that real-world categories have much relational structure, as well as much prior knowledge, it is unclear how well these findings will relate to more complex cases.

## 2.29.3 Beyond Classification and Featural Representations

In this section, we consider some recent work that begins to address these limitations. First, research has extended concept and category learning from a focus on classification to consider other means of category learning. Second, we consider two formal models that were designed to examine category learning beyond classification, the Rational Model and SUSTAIN. Third, we review some work that has gone beyond representations of features to ask how more complex categories might be learned, including the influence of prior knowledge. Finally, we consider how far this new research has gone in providing a resolution, or at least a partial resolution, to these limitations.

### 2.29.3.1 Category Learning Beyond Classification

As we outlined at the beginning, concepts and categories have many functions, of which classification is just one. Classification is an important one: By determining what category an item is in, one has access to much relevant knowledge about that item. However, the near-exclusive focus on classification learning in laboratory experiments is problematic for two reasons. First, if we learn categories in multiple ways, it seems prudent to examine more than classification learning to get a full understanding of category learning. Second, classification learning has an important difference from most other conceptual functions. In classification learning, the goal is to determine what category the item is in. This requires figuring out what distinguishes the competing categories. However, most other functions, such as prediction, understanding, or communication, require using what you know about a particular category, with the other categories often not mattering at all. That is, classification requires distinguishing between categories, but most other functions require within-category knowledge. For example, Chin-Parker and Ross (2004) found that classification learning led to learning only about diagnostic features (those that are predictive of category membership). People learned nothing about the other features that were not predictive of a category, even though they occurred 80% of the time in both categories. This result is exactly as predicted by classification theories, such as the exemplar models mentioned earlier (e.g., Nosofsky, 1986). However, if one is predicting what a new animal eats, it requires knowing more than what type of animal it is; one also needs to know what food is eaten by animals of that type. If one is solving a math problem, knowing the type of problem is helpful only if it allows access to relevant information about how to solve problems of that type.

A number of laboratory tasks have been examined over the last 10 years that extend our understanding of category learning by examining types of learning other than classification. These tasks emphasize how categories allow us to accomplish the goals we have: Predict, solve problems, explain. We focus on three tasks here: Inference learning, in which the classification is provided; category use, in which the learner uses the category to learn some other task; and an unsupervised learning, in which no category information is provided. We give a rough outline of their procedural differences from classification learning in **Table 4** and a rough outline of the processing in **Figure 2**.

First, one can learn about categories by inferring features of category members. Inference learning is a

**Table 4** Simplified procedures for various category-learning laboratory tasks

| | |
|---|---|
| Classification | An item is presented<br>Subject responds with one experimenter-defined category label<br>Feedback given on classification<br>Next item is presented |
| Inference | An item (one feature missing) is presented, along with category label<br>Subject responds with value of missing feature<br>Feedback given on inference<br>Next item is presented |
| Category use | An item is presented<br>Subject responds with one experimenter-defined category label<br>Feedback given on classification<br>Subject uses category and item to do some task (inference, problem solve)<br>Feedback given on second task<br>Next item is presented |
| Unsupervised[a] (using Minda and Ross, 2004, to be specific on procedure) | An item is presented<br>Subject uses item to do some category-related task (prediction)<br>Feedback given on task<br>Next item is presented |

[a]Note: no mention made of category, but category is useful for prediction.

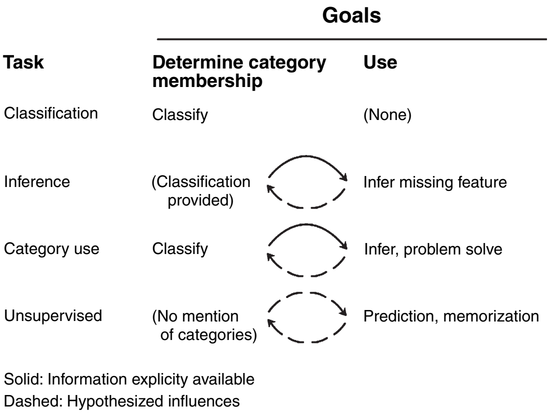


**Figure 2** Schematic to illustrate the relation among the different laboratory tasks used to study category learning.

paradigm that can be compared to classification directly: Rather than presenting *N* features and asking what category the item is in, the label is given along with *N*−1 features, and the person's task is to supply the missing feature (Yamauchi and Markman, 1998). Suppose there is an item in Category A that has three features; we can characterize this item as {A a1 a2 a3}. In a classification trial, the learner would be provided with {? a1 a2 a3} and have to provide the label A, whereas in an inference trial, the learner would get {A a1 a2 ?} and have to provide the missing feature, a3. The procedure is presented in **Table 4**. This task matches a common means of interacting with categories in which one knows the category and parts of the item but has to infer a missing feature: Given this dog, what will it eat? Or given this type of situation, what will happen next? This task appears to be very similar to classification learning but leads to rather different learning. In inference learning, people learn prototypical features that are not diagnostic (Chin-Parker and Ross, 2004) and features that vary in their exact presentation (Yamauchi and Markman, 2000). Focusing within a category leads people to learn what the category is like, not just what distinguishes it from another category (Yamauchi and Markman, 1998; see Markman and Ross, 2003, for a review; Johansen and Kruschke, 2005, for counterarguments). However, if one knows what a category is like (e.g., dogs, permutations), one can often tell if an item is a member of the category as well. In addition, inference learning, by focusing on what the category members are like, may also help people to understand the underlying coherence of relational categories (Erickson et al., 2005).

Second, other work has considered classification as part of a larger goal-related task and asked how category knowledge might be influenced. The rationale is that classification is not usually the goal; usually we want to do something with the classification. We classify an object as a pencil and use it to write, a person as a psychopath and stay away, a math question as a permutations problem and apply the appropriate formula. Ross (1997, 1999, 2000) has conducted research with a category use paradigm in which one not only classifies the item but also then uses the item to perform some goal-oriented task, such as make an inference about the item or solve the problem (see **Table 4** and **Figure 2**). In these studies, the uses of the category (e.g., inference or problem solving) influence the category representation, even for later classification. Performance on later classification tests is not a function just of the diagnosticity of the features but also of their importance for the use. Those features involved in the inference, for example, are viewed as more central to the category than equally predictive features that are not involved in the use. To be more concrete, Ross (1997) had people learn to classify patients (sets of symptoms) into two diseases and then choose the treatment to give that patient (which depended on both the disease and the symptoms). Two symptoms were equally and perfectly predictive of the disease, but only one was also predictive of the treatment. After learning, people were given a single symptom and asked which disease they would think a patient had if this was all they knew of the symptoms. Although both symptoms were perfectly predictive of the disease, learners were much more likely to correctly classify the one that was also predictive of the treatment. Even when we explicitly classify items, we continue to learn about the category from other nonclassification uses, and this knowledge influences a variety of later category-related judgments, including classification. Related results have been found with problem solving (Ross, 1997, 1999), and even with young children (Hayes and Younger, 2004; Ross, et al., 2005).

The goals for which categories are used during learning can have additional consequences that may influence the representation of real-world categories. Brooks et al. (2007) argue that tasks in which classifications are used for a different primary task may lead to a very different learning of the classification knowledge than classification alone. In a clever set of experiments, they show that the other task diverts attention away from analyzing the category structure for classification, such that learners believe the category has defining features when it does not. When we divert our resources to using the category, the knowledge learned from the classification may be a less central part of our category representation.

Third, we can look at cases in which people are not even told there are categories. If we have a helpful teacher/parent, we may get feedback on the category membership (classification) or labeled items (inference), but in many cases, such as much of our informal learning, we may not. In unsupervised learning tasks, the categories are not provided to the learner (e.g., Ahn and Medin, 1992; Heit, 1992; Wattenmaker, 1992; Clapper and Bower, 1994; Billman and Knutson, 1996; Kaplan and Murphy, 1999; Clapper and Bower, 2002; Love, 2003). Here, the particular interactions people have with the items may affect later formation of categories (e.g., Lassaline and Murphy, 1996). Many of these unsupervised tasks focus on the items and the categories, often through observation, memorization, or sorting. When there is a more goal-oriented learning task, such as predicting a critical feature or solving a problem, any learning about the categories or items is incidental to attaining the goal. Minda and Ross (2004) found in a prediction task (where category membership was crucial to the prediction) that the unsupervised learning led to paying more attention to a wider set of features than did classification learning.

In sum, although classification learning has been the dominant paradigm for studying category learning, including other tasks may provide a more complete picture of category learning. Classification is a critical function of categories, but it is critical because it provides access to knowledge about the item that can be used to infer, predict, understand, or explain. Classification learning promotes learning what distinguishes the categories, whereas these other functions of categories tend to promote learning what each category is like.

### 2.29.3.2 Formal Models That Do More Than Classify: Rational Model and SUSTAIN

Most category-learning models have focused on classification learning, but a few have considered other category functions. We consider two prominent models, J. R. Anderson's (1990, 1991) Rational Model of categorization and SUSTAIN (Love et al., 2004), with an emphasis on learning mechanisms and extensions to multiple functions of categories.

#### *2.29.3.2.1 The Rational Model of categorization*

The Rational Model is a component of Anderson's (1990, 1991) rational analysis of cognition. The central claim of the model is that categories serve as a basis for prediction. Classification is a specific type of prediction in which the task is to predict the category label. The model stores clusters of exemplars with similar properties. The primary goal of the model is to develop clusters that optimize the accuracy of a variety of category-based predictions.

Predictions in the model are based on conditional probabilities. The probability that a new exemplar with a set of properties $F$ has property $j$ (on dimension $i$) is:

$$P_i(j|F) = \sum_k P(k|F)P_i(j|k), \quad [1]$$

where $P(k|F)$ is the probability that an item belongs to cluster $k$ given that it has properties $F$, and $P_i(j|k)$ is the probability that an item in cluster $k$ has property $j$ on dimension $i$. The idea behind equation 1 is that predicting a missing property involves the summing of probabilities across multiple clusters, with the influence of each cluster weighted by its probability, given the new item. The sum of these values across all clusters is the probability that the new item has property $j$.

Clusters are learned that optimize the accuracy of predictions. The first exemplar forms its own cluster, and each added exemplar is either placed into an existing cluster or a new one that contains only itself, whichever maximizes within-cluster similarities. Thus, a new item that is dissimilar to the earlier items is more likely to begin a new cluster. The probability that a new item will be placed into cluster $k$ depends on (1) how similar the item and cluster features are and (2) the size, or base rate, of the cluster, with the item more likely to be placed into a cluster that represents more items.

Two aspects distinguish this model from the classification models described earlier. First, clusters differ from prototype and exemplar representations in that the goal of clustering is more abstract: to capture statistical structures in the environment suitable for making predictions. Interestingly, clusters sometimes mimic each of the other approaches (cf. Nosofsky, 1991), suggesting that aspects of both prototype and exemplar representations are useful.

Second, the model predicts features as well as category labels, so it can be used for nonclassification tasks, such as inference learning (see Yamauchi and Markman, 1998). In addition, it provides an explanation for how people might induce a missing feature of an exemplar when the category is unknown. Suppose that you hear an animal rustling behind a bush, and you think it is probably a dog but possibly a raccoon. What is the probability that the animal barks? In terms of equation 1, dog and raccoon are different values of *k*. Murphy and Ross (1994, 2005; Malt et al., 1995; Ross and Murphy, 1996) tested this hypothesis in a large number of studies and usually found evidence against it. Their work shows that people instead tend to base predictions on the most likely category only (dog in the previous example). Although the Rational Model was not supported, it provided a strong alternative view and has led to a consideration of when single categories and multiple categories might be used for predictions.

#### 2.29.3.2.2 SUSTAIN

SUSTAIN (Supervised and Unsupervised STratified Adaptive Incremental Network; Love et al., 2004) is a network model of category learning that shows great flexibility compared with prototype and exemplar models for two main reasons. First, like the Rational Model, it seeks to build clusters that capture regularities or structure in the environment. Second, unlike the Rational Model, this search for structure is guided by the goals of the learner. This goal-oriented learning allows the model to account for a wide variety of category learning results beyond classification.

Categories in SUSTAIN are represented by clusters. Unlike the Rational Model, these clusters are not collections of exemplars but, rather, summary representations of encountered exemplars. The clusters formed are influenced by the goals of the learner, such as increased attention to the feature (including category label) being predicted and the features most relevant for this prediction. The details of the model are complex, so we outline the main steps of performance and learning here, then turn to a simple example.

The performance, such as prediction of a feature, relies upon the clusters. The item is compared to each cluster, and the most similar cluster determines the prediction. The summary representation of each cluster includes a distribution of expectations for each dimension (e.g., how likely the different values are to occur). The item's features are compared to these various distributions, with selective attention occurring through the tuning of receptive fields on each dimension (akin to visual receptive fields that are, for example, sensitive to a small range of orientations at particular locations). The activation of the cluster increases with the similarity of the item's features to the summary representation (weighted by the selective attention weights). The different clusters can be thought of as trying to explain the input for the particular goal, with lateral inhibition among the clusters leading to a winning cluster that determines the output. Thus, unlike the Rational Model that sums over all the clusters (see equation 1), only the most likely cluster is used to determine the prediction (consistent with the Murphy and Ross, 1994, results).

SUSTAIN is biased toward simple category representations (i.e., few clusters) but does develop more elaborate clustering schemes for complex stimulus sets. Learning involves updating old clusters and developing new ones. In supervised learning, if the correct prediction is made, SUSTAIN will compare the output of the winning cluster to the target response and make small adjustments in receptive field tunings and summary representation values in the direction of the target values, if needed. These changes will lead to a repetition of the item producing a cluster output closer to the target values. If an incorrect prediction is made, a new cluster is created that is centered around the item. (In unsupervised learning, a new cluster is formed if the current item is not sufficiently similar to any existing cluster.)

This explanation is a bit abstract, so we illustrate with a simple example. Imagine there is an object that can be described by three binary features: shading (filled = 0, empty = 1), color (blue = 0, red = 1), and shape (circle = 0, triangle = 1). Thus, we can represent an (empty red circle) as (1, 1, 0). Suppose this was the first item presented, then Cluster 1 (CL1a) would simply be (1, 1, 0) as seen in **Figure 3**. Now suppose the second item was (empty red triangle), item (1, 1, 1), and it was similar enough to be put in the same cluster. The updated Cluster 1 (CL1b) would be adjusted to be (1, 1, 0.5). The last value does not represent a triangular circle but, rather, an increased probability that a new item represented by that cluster will be a triangle. If the third stimulus (empty blue circle), (1, 0, 0), is not sufficiently similar to CL1b (unsupervised learning) or does not predict the correct response (supervised learning), the model recruits a new cluster CL2a to represent that item, as shown in the figure.

Recall that SUSTAIN prefers simple cluster sets when possible. To demonstrate, if the stimuli in **Figure 3** were divided by shape into two categories, it is likely that SUSTAIN would develop two clusters, each at the center of the front and back face of the cube, (0.5, 0.5, 0) and (0.5, 0.5, 1). These would indicate a high probability of circle//triangle for the front/back cluster and intermediate probabilities for other dimensions. This is a simple clustering solution, because it strongly emphasizes just one feature.

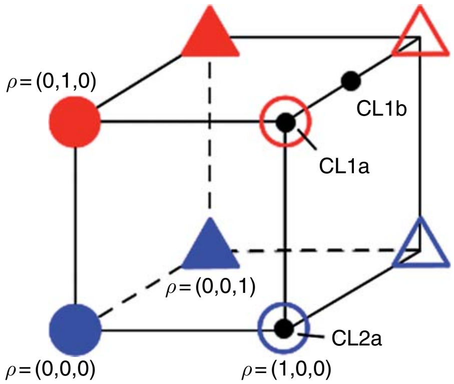


**Figure 3** Binary-valued stimuli to illustrate working of SUSTAIN. Coordinates are shading (0 = filled, 1 = empty), color (0 = blue, 1 = red), and shape (0 = circle, 1 = triangle). Black dots represent clusters CL1a, CL1b, and CL2a following the presentation of items (1, 1, 0), (1, 1, 1), and (1, 0, 0), respectively.

Like the Rational Model, the clusters in SUSTAIN adapt to their learning environment, but they are also sensitive to the goals of the learner (e.g., Barsalou, 1985; Solomon et al., 1999; Medin, et al., 2006). In supervised learning, new clusters are created in response to an incorrect decision, allowing the model to adjust to specific learning criteria. This differs from clustering in the Rational Model, where new clusters are created in response to exemplars that are generally dissimilar to existing clusters.

SUSTAIN's ability to adapt to different category functions is also seen in comparing classification and inference learning. Using a family resemblance structure (where all items are similar to a prototype for the category), Love et al. (2000) found that inference learning often led to a single cluster (i.e., close to the prototype), whereas classification tended to create several clusters per category, indicating the use of simple rules and memorization when classifying. (See also Love and Gureckis, 2005, for a related application to a real-world difference in goals.)

In summary, SUSTAIN focuses on the relationship between learning goals and category structure. In a sense, SUSTAIN generalizes the contributions of the Rational Model by proposing that, in addition to capturing the structure of the environment, categories also capture a learner's goal-specified relationship with the environment.

### 2.29.3.3 Beyond Featural Representations

Much of the current work on category learning is limited not just in how the categories are learned but also in what is learned. The categories learned in these studies are different from real-world categories in two important ways. First, the category structure is feature-based with only very simple relations among the features. Most, if not all, real-world categories have much more complex structures, and relations are essential. Second, the materials are usually devised to make as little contact with any world knowledge as possible, to allow an unconfounded examination of category learning. However, the learning of most (and perhaps all) real-world categories is influenced by our world knowledge: By minimizing the influence, we may be ignoring a major influence in the learning. We discuss each of these ideas with a brief examination of relevant models.

#### *2.29.3.3.1 Relational information*

Most of the categories studied in experimental settings with adults consist of a small number of features (usually 2–5), with some of the features predictive of each category. These simple structures, cleverly designed, are often sufficient to provide tests of particular aspects of current formal models. The underlying (implicit) assumption is either that real-world categories have such structures (which they do not) or that the learning principles derived from studying such simple structures will apply to learning more complex structures. This latter possibility remains feasible, though we present evidence throughout this section suggesting that there are many important differences. The main point we wish to make here is that the category structures that have typically been examined are a very small subset of the possible structures and do not have much to do with real-world category structures (see Murphy, 2005).

Let's take a simple example of relational structure, within-category correlations. We can classify an item as a bike using features such as handlebars, tires, and such. Bicycle handlebars include ones that are either dropped or straight, and bicycle tires include ones that are knobby or slick. However, these are not independent features: Dropped handlebars and slick tires usually go together (racing bikes), as do straight handlebars and knobby tires (mountain bikes). These within-category correlations are common in many real-world categories: They do not add to the category predictiveness of the features, but they are important as signals to additional category structure, such as subcategories. When within-category correlations have been examined in laboratory studies of classification learning, they do not appear to be learned easily, if at all (Chin-Parker and Ross, 2002). This difficulty is generally consistent with classification learning models, because the within-category correlations do not improve the classification predictiveness. Despite this unanimity of classification models and laboratory classification learning data, people do learn within-category correlations in the world. They even learn it in the laboratory when given inference learning (Chin-Parker and Ross, 2002) or when prior knowledge promotes the correlation (Murphy and Wisniewski, 1989).

The point is that as one moves to more complex relations among features, we know little about category learning. Of course, the structure of real-world categories is far more complex than a single within-category correlation: Imagine the structure for carrots or permutations. The dominant classification models are all feature based and do not allow for complex relational information (though see Pazzani, 1991). The problem is that adding relational information greatly complicates models and brings a host of additional issues that need to be addressed (e.g., Hummel and Holyoak, 2003).

#### *2.29.3.3.2 Knowledge*

What people know affects what they learn: Cricket fans gain much more from watching a cricket match than do those of us who know nothing about the game. Not surprisingly, the effect of knowledge is also true in category learning: Knowledge can have large effects on the ease of learning as well as what is learned (see Murphy, 2002: chapter 6, for a review). Continuing the example on within-category correlations, knowledge has a large effect. Murphy and Wisniewski (1989) had people learn categories containing within-category correlations. For example, their materials included correlated features that were conceptually related (for a clothing category: worn in winter, made of heavy material) or not (blue, machine washable). They found that in the absence of knowledge relating the features, classification learners did not learn these within-category correlations. However, in the condition in which knowledge related the features, classification learners did show sensitivity to the correlations. Ahn and her colleagues argue that there are so many possible correlations in the world that people cannot notice all of them, so people use their knowledge to notice correlations that are meaningful to them (e.g., Ahn et al., 2002; though see McRae, 2004).

We mention briefly three other effects of knowledge on learning. First, the learning of new categories that are consistent with prior knowledge is greatly accelerated compared with learning unrelated or inconsistent categories. For example, Wattenmaker et al. (1986) showed that categories consisting of items whose features related to a theme such as honesty (e.g., returned the wallet he had found in the park) were faster to learn than categories whose items had unrelated features. Second, even learning to classify items into categories consistent with knowledge but for which a prior concept is unlikely to be available (e.g., arctic vehicles) is faster than learning to classify into unrelated categories (e.g., Murphy and Allopenna, 1994). Third, the learning influence of prior knowledge does not restrict learning to only those features related to the prior knowledge, but generally, those are learned more quickly than the unrelated features of the items (e.g., Kaplan and Murphy, 2000).

How does knowledge influence category learning? Wisniewski and Medin (1994) suggest three important possibilities (also see Heit and Bott, 2000). First, knowledge might weight or select features of the item. Second, knowledge might allow one to infer additional, relevant features. Third, although these first two possibilities view knowledge as independent of the learning process, knowledge and learning may be more tightly coupled or interactive. Learning may influence the activated knowledge, which may then influence later learning. As one example, learners might begin to change how they interpret some features as they see how the features relate to their goal. The main point of this work is that knowledge and concept/category learning cannot be thought of separately: Our knowledge of particular concepts is intimately intertwined with other knowledge, and we use that other knowledge both to help learn new information about concepts and that this learning in turn may influence our other knowledge.

Despite this large influence of knowledge on category learning, most category learning research has examined cases in which knowledge influences are minimized (Murphy, 2005). If there are interactions between the influences of knowledge and the learning, some (unknown) part of what we learn from examining category learning in the absence of knowledge may not be applicable to the cases in which knowledge is used. In addition, there may be learning processes with knowledge that are not required in the knowledge-free classification learning experiments.

There has been some progress in considering how to account for the influence of prior knowledge on category learning in a more general way, including

Heit's Baywatch model (Bayesian and empirical learning model, e.g., Heit and Bott, 2000) and KRES (Knowledge-Resonance model; Rehder and Murphy, 2003). Space precludes much description of these complex connectionist models, but both models add nodes to represent prior knowledge in addition to the usual ones to represent the features of the items. The presented item activates its features but also activates prior knowledge that it is related to, providing an additional source of activation for the category decision. The models account for a wide variety of data. For example, KRES predicts that the learning of categories consistent with prior knowledge is accelerated compared with unrelated categories, and even features unrelated to the prior knowledge are learned. In addition, this model incorporates the interactive view between knowledge and learning by the learning influencing the connection weights between features and between features and prior knowledge.

These models of prior knowledge do not include relational representations. Relational models are beginning to be developed (e.g., Hummel and Ross, 2006; Kemp et al., 2006; Tomlinson and Love, 2006) but need also to address the pervasive influences of prior knowledge.

#### 2.29.3.4 Directions for Providing Integration

We have considered some limitations of the current category learning work both in terms of the learning tasks and in terms of the featural representations. Different means of learning about categories provide a variety of knowledge about the category not just for classification but also to support all the category-based cognitive activities. In addition, the knowledge about a category has to be intimately related to our other conceptual knowledge to be useful. What does this suggest about concept and category learning?

A main lesson that we have taken from a consideration of these various limitations is that the study of concepts and category learning needs to be integrated into other areas of cognition. Conceptual knowledge needs to support many cognitive activities, not just classification, and examining these category-based activities across a variety of domains will both point out places in which we need to further our understanding of category learning and help to make the work on category learning more relevant to other areas of cognition. Much of our learning depends on our goals, so considering more than category learning is an important part of ensuring this integration.

Murphy and Medin (1985), in a seminal paper, proposed that the study of conceptual structure could not rely on similarity to explain why objects might cohere, or go together, in a category. Although similarity might be a useful heuristic in some cases, it is too unconstrained to provide an explanation of category coherence. They proposed that the coherence of the category depended on its fit to people's prior knowledge – the naive theories people have. This proposal changes the idea that the category members are similar to that they have some similar underlying rationale. Their internal structure is defined not just by features but also by relations connecting features. In addition, their external relations are critical: They must relate somewhat consistently with other knowledge the person has. This view is often called the theory view to make clear that it views category coherence as depending upon people's theories, not simple similarity.

This proposal has had a major influence on how conceptual structure is thought about and investigated. It was instrumental in leading to much of the work on how knowledge influences category learning. We mention two interesting illustrations. First, Wisniewski and Medin (1994) gave subjects a set of children's drawings of people and asked them to provide a rule for each category; they were told either that one group of drawings was from creative children and the other from noncreative children or, for other subjects, that one group was from city children and the other from farm children. The rules generated were very different, picking up on aspects of the drawings that were consistent with some ideas of those types of people. For example, one feature was seen as a pocket, indicating detail, when it was from the drawings by creative children, but was seen as a purse when it was from drawings of city children. Second, Ahn and Kim (2005; Kim and Ahn, 2002) have examined clinical psychologists' understanding of various psychodiagnostic categories (such as depression or anorexia). Although the training they receive emphasizes a prototype representation (classification is often in terms of some criterial number of features being present), the clinical psychologists often apply their causal theories of the disorders to help diagnose and determine treatments. Thus, this theory view has led to a wealth of interesting research relating prior knowledge to concept learning. The main shortcoming of this view is the lack of specific details on how knowledge influences learning.

There are likely to be many cases in the learning of complex categories in which the constraints imposed by theories are not sufficient even for classification. For example, in learning to classify members of many real-world categories, there may be hundreds of potential features that could be important for determining category membership, so what determines which features people use? Knowledge may reduce the number of likely features and relations but still leave too large a number to consider. One possibility is that the importance of the features and relations for the overall goal of the task may provide a heuristic as to which ones are important for classification. For example, one might not be able to tell how to classify a particular math problem, but as one gets experience solving problems of that type, those aspects of the problem critical for solution may provide a good clue as to how to classify future problems. The comparison to other category members with respect to these useful features may also help to lead to a deeper understanding of why the problem is solved in this way.

It is important to clarify this suggestion and make clear how it relates to the general integration goal of this chapter. Concepts and categories support a variety of functions. The usefulness of this knowledge across the different functions provides constraints that one cannot get from a single function. In addition, the changes to the representations as one both uses and gets feedback on one function provides knowledge that can be used for other functions. For example, learning to classify complex items, with many features and relations, is a very difficult task if one relies only on feedback from the classification (which may be why classification learning experiments typically use few features and values). However, if these same categories are used for inferences or problem solving, that use provides suggestions as to what features and relations one might consider. Similarly, background knowledge can be used to help focus on relevant features and relations or even to learn new features that are important for later classifications (e.g., Wisniewski and Medin, 1994). The apparent difficulty of learning complex concepts is partly a result of thinking about it as some isolable process that relies only on classification and feedback on the classification. People have many sources of information from both the various interactions with the items and their prior knowledge to help in learning new concepts and categories.

## 2.29.4 Integrating Concepts and Categories into Cognition

We have been arguing throughout this chapter that it is important to think about concept and category, learning more broadly to integrate it into the many cognitive activities in which they play such a critical role. In this section, we illustrate this possibility by examining concepts and categories in two very different areas, problem solving and language.

### 2.29.4.1 Problem Solving

Categories play a critical role in human problem solving. Being able to correctly classify a problem as a permutations problem allows you to recall and apply the appropriate formula. In this section, we describe how category knowledge can influence various aspects of the problem-solving process, how problem categories change with experience, and how problem solving can affect the category representation.

Most models of problem solving consist of some version of the following five stages: (1) problem identification and creating a mental representation of the initial problem state and goal; (2) identifying and selecting a set of operators, procedures, or strategies to make progress toward that goal; (3) applying those operators and generating a solution; (4) assessing whether the solution satisfies the goal; and (5) storing the solution with other knowledge about the problem/category (Newell and Simon, 1972; Bransford and Stein, 1993; Pretz et al., 2003).

Categories impact all aspects of this process and are especially critical in the early stages (**Figure 4**). The process of problem identification is a classification that determines whether or not the current problem is like other problems encountered in the past. After the problem is classified, the problem solver can then recall and apply a set of procedures, strategies, or rules to solve the problem, such as recalling the appropriate formula for a permutations problem. Category knowledge may also be helpful in later stages of problem solving, such as evaluating whether or not a potential solution satisfies the known constraints of the problem type.

The problem goal is also important. Since category knowledge is used in the service of accomplishing some particular task, knowing how the goal relates to the problem features is a critical part of understanding the problem and identifying the appropriate solution procedures to solve it. As an illustration,

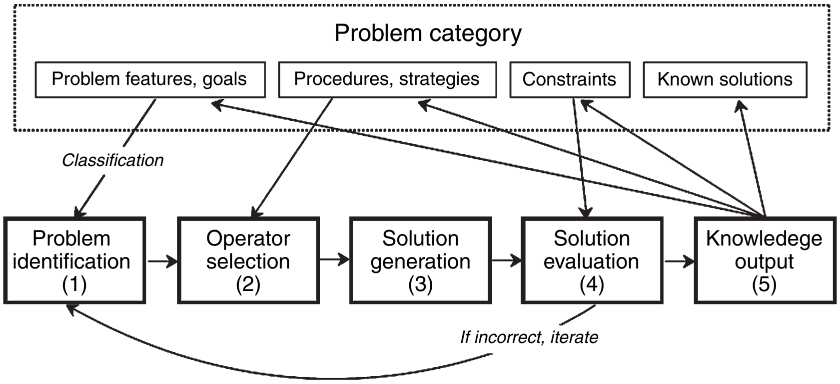


**Figure 4** Five stages of problem solving (lower boxes) and relation to knowledge of problem categories (upper box). Arrows connecting boxes in the lower portion of the figure represent the general order of processing. Arrows connecting boxes between the upper and lower portions represent interactions between problem solving and category knowledge.

imagine that, as you are ready to drive to work, you notice the lights were left on, and the car does not start. If you classify the situation as a dead car battery, you can search your relevant category knowledge, perhaps recalling that one solution is to use jumper cables and ask your next-door neighbor for a jump. However, if your primary goal was to get to work on time, you might access other relevant knowledge such as calling a friend for a ride. For categories to be helpful for problem solving, they must go beyond simple diagnostic features and include information about the problem or goal procedures or strategies to accomplish that goal, and knowledge to evaluate the solution.

#### *2.29.4.1.1 Differences between expert and novice category representations*

Much research has shown that experts categorize problems with the principle or structural features of the domain, whereas novices rely on using the surface features (Larkin et al., 1980; Bedard and Chi, 1992). Chi et al. (1981) found that when physics experts were asked to sort a set of problems into those that could be solved similarly, they sorted on the basis of the underlying physics principles, such as Newton's Second Law, whereas novices sorted on the basis of the surface characteristics, such as problems with inclined planes. The physics experts had learned to associate the deep principles with the problem features and could take advantage of this knowledge for problem categorization.

The finding that experts use the deep principles of the domain to classify and reason about novel problems has been shown in many other domains including chess (Chase and Simon, 1973; Gobet and Simon, 2000), computer programming (Adelson, 1981), electronics (Egan and Schwartz, 1979), and mathematics (Silver, 1979, 1981), among others. How does one go from a novice category representation to that of an expert? One suggestion from the problem-solving literature is that much of the learning comes as a by-product of the problem-solving activity itself (Ross and Kennedy, 1990; Cummins, 1992). There are multiple possibilities for how this can occur, including adding new knowledge to the category, modifying previous knowledge by weighting particular category features, adding constraints to the category to further specify the category boundary, deleting inappropriate knowledge, or acquiring new, more specific categories. These possibilities suggest not only that categories are a critical aspect of human problem solving but that category representations can be adapted and changed through problem solving.

#### *2.29.4.1.2 Problem solving and category learning*

Much experimental work shows that problem solving can affect category learning (Ross, 1996, 1997, 1999). For example, Ross (1996, Experiment 2a) conducted a category use experiment (similar to the ones mentioned in the section 'Beyond classification and featural representations') in which students learned to classify equations into two categories and then solve them. The solutions of the equations differed, and the question was whether this would affect the participants' category representations and influence their future classifications. **Table 5** shows a sample of the materials. Every problem had an $x$ and a $y$ variable, and half of the participants solved for variable $x$ and the other half for variable $y$. The equations were

**Table 5** Sample materials from Ross (1996)

| *Phase of experiment* | *Equation* | *Solution* | *Solve for* x | *Solve for* y |
|---|---|---|---|---|
| Study | | | | |
| Type 1 | $9 + \frac{sx}{t} = \frac{5qy + b}{f}$ | | SMD | MSD |
| Type 2 | $sp + \frac{ry}{2} = \frac{g + 9x}{b}$ | | MSD | SMD |
| Test | | | | |
| | $k + \frac{9z}{a} = \frac{s + r}{t}$ | SMD | Type 1 | Type 2 |
| | $s + \frac{2}{n} = \frac{9 + mz}{p}$ | MSD | Type 2 | Type 1 |

SMD, subtract, multiply, divide; MSD, multiply, subtract, divide. At test all subjects solved for *z*. The ''solve for *x*'' and ''solve for *y*'' labels refer to the study conditions.

From Ross BH (1996) Category representations and the effects of interacting with instances. *J. Exp. Psychol. Learn. Mem. Cogn*. 22: 1249–1265. Copyright 1996 by the American Psychological Association. Reprinted with permission of the author.

created so that those who solved for variable *x* would use a subtract-multiply-divide (SMD) solution procedure on type 1 problems and a multiply-subtract-divide (MSD) solution procedure on type 2 problems, whereas those who solved for variable *y* would use the opposite procedures on the two problem types. At test, they classified novel test problems and solved for a new variable *z*. Tests requiring a SMD solution procedure tended to be classified as type 1 problems for those participants who solved for *x* and as type 2 problems for those who solved for *y* (and vice-versa for test problems that required the MSD solution procedure). Although the two groups classified the same problems into the same categories during learning, they classified the test items into opposite categories because of how they interacted with the items. The way in which problems are solved can influence which categories people have.

Beyond traditional problem solving, Medin and colleagues show strong influences of extended interactions on how tree experts classify and reason (Medin et al., 1997; Lynch et al., 2000; Proffitt et al., 2000). Taxonomists and maintenance workers sorted a set of trees on the basis of morphological features, but each weighted the importance of those features differently, whereas the landscapers sorted more on the basis of utilitarian features, such as providing shade or ornamental quality (Medin et al., 1997). The experts' category representations were influenced by how they interacted with items in the category. Proffitt et al. (2000) found that all of the groups used ecological-causal domain knowledge in addition to general taxonomic knowledge to make inductions. These results are consistent with the laboratory results showing that experience interacting in a domain influences a person's category representation and subsequent reasoning from those categories.

The role of concepts and categories in problem solving is pervasive. For categories to be useful for problem solving, they require more than simple featural representations, including information about the goals, solution procedures, and constraints of the problem. Problem categories change with experience: There are general shifts from surface feature representations to structural (relational) representations, as well as influences of the particular uses.

### 2.29.4.2 Language

Categories are also critical in language use. We focus on one area within language performance (i.e., the encoding of syntactic number) to explore different kinds of categories, the processes that operate on them, and the functions such categories serve in language performance.

In general, the types of categorical structures necessary to support language processing seem to depart considerably from those focused on in category learning research. For example, during language production, transforming a message that is full of meaning into an utterance that is full of sound (Bock and Miller, 1991) may involve (at least) coordinating systems of categories corresponding to syntactic structure (e.g., the syntax of phrases or sentences), grammatical functions and thematic roles (e.g., subject, object, agent, patient), word types (e.g., noun, verb), word-specific grammatical information (e.g., grammatical gender and number), word meanings, morphophonology, and prosodic structure. Particular to syntactic number, the production of a lexical singular (e.g., cat/argument/dustbuster) or a lexical plural (e.g., cats/arguments/dustbusters) is thought to be rooted in a kind of categorization involving the apprehension of the referent of a noun as a single thing or more than one thing (Eberhard et al., 2005). Some categorizations are not simple: A bowl full of "fresh or dried food that is usually made from flour, eggs, and water formed into a variety of shapes" may be conceived of as a mass or as comprising individual units and so the speaker may elect to call it pasta or noodles, respectively. This categorization determines the appropriate lexical number characteristics of the noun.

Consistent with our emphasis on category use, assigning lexical number (singular or plural) is not an end in and of itself – lexical number characteristics serve the function of communicating to a listener the numerosity of referents, and they are critical in the computation of grammatical agreement (such as between a subject and a verb; Eberhard et al., 2005; but see Vigliocco et al., 1996). Grammatical agreement in turn serves important communicative functions such as linking pronouns to their referents and helping listeners syntactically bind subjects to their predicates when syntactic ambiguity arises. For example, subject–verb agreement helps disambiguate who has rabies in "The *dog* chasing the *men* that *has* rabies."

Beyond categorizing a referent as one thing or more than one thing, singular nouns in many languages divide into count nouns and mass nouns. The count/mass distinction is thought by some to reflect distinct modes of construal relevant to individuation and allows an interesting examination of concepts in language use.

Count nouns like animal(s), argument(s), and noodle(s) must have a determiner in the singular form (*Animal is fierce), are regularly pluralized, and take the quantifiers many and few. Mass nouns such as wildlife, evidence, and pasta do not need to take a determiner in the singular (Wildlife is flourishing), are not regularly pluralized, and take the quantifiers much or little. What are the psychological implications of this distinction? The cognitive individuation hypothesis proposes that count nouns denote individuated entities and mass nouns denote nonindividuated entities (Mufwene, 1984; Wierzbicka, 1988; Jackendoff, 1991; Bloom, 1994; Bloom and Kelemen, 1995; Bloom, 1996; Wisniewski et al., 1996; Wisniewski et al., 2003; Middleton et al., 2004). The class of individuated entities includes common objects such as cats, blenders, and airplanes but also includes things bounded spatially (even to an absence of matter, e.g., a hole, Giralt and Bloom, 2000) or temporally (events, such as a footrace or a party; Bloom, 1990). Individuation can apply to entities linked by common fate or goal (e.g., a gang, a flock) or common purpose (a bikini may be conceived as an individual because the two pieces perform one function; Bloom, 1996), as well as from a variety of other factors (see Goldmeier, 1972; Jackendoff, 1991; Soja et al., 1991; Bloom, 1994).

#### *2.29.4.2.1 Categorization and cognitive individuation*

The process of individuation is not just a categorization based on the physical features on an entity. Cognitive individuation involves active construal of an entity, which can be flexibly applied and has important consequences. Specifically, if a person individuates an entity, that person predicates that features of the entity must hold specific functional relationships to each other (Wisniewski et al., 2003; Middleton et al., 2004). For example, if one individuates a configuration of wood as a table, one is comprehending how the configuration of four upright pieces of wood and a horizontal wooden plane go together to support the important function of supporting stuff. This construal does not allow pieces to be randomly removed or rearranged. In contrast, if one categorizes the table as a nonindividuated entity, one might focus on the material rather than the configuration. If so, one might predicate the important property of 'is flammable,' which does not depend on the configuration.

Evidence that individuation is a flexible process in which different outcomes (e.g., individuation vs. nonindividuation) can arise given the same stimulus was reported by Middleton et al. (2004; Experiment 4). One group of participants viewed a bounded pile of coarse decorative sugar in a box (a novel stimulus) and chose to refer to it with count or mass syntax. A second group viewed the stimulus, followed by a mode of singular interaction where they repeatedly took an individual grain and placed it through one of several holes in a rectangular piece of cardboard. Participants in this second group were more likely to refer to the stimulus with count syntax than the control group. This demonstrates that individuation is not directly tied to the features of a stimulus. Rather in this case, how a person interacted with the entity was related to its individuation status, and this in turn was reflected in the syntax they used. This point introduces the functionality of the count/mass distinction: Using count or mass syntax provides a means to communicate distinct construals of an entity in terms of individuation. This may be particularly useful when the mode of construal as an individual or nonindividuated entity is atypical for a referent. Consider 'too much woman' as in "[S]he's [Jennifer Lopez] too much woman for that piece of snore [Ben Affleck]." Using mass syntax with what is typically a count noun (i.e., woman) allows the speaker to communicate construal of womanly attributes as lying on a continuum, with Jennnifer Lopez falling on the high end (at least, too high for Ben Affleck). Attributes of other common objects can be construed as lying on a continuum, as communicated in "[M]any border collies are destroyed because they proved to be too much dog for their owners," where 'dogness' may be some value along a continuum composed of activity level, obedience, ferocity, and so on. (These examples are extracted from American Web sites.)

Language may not just reflect concepts, it may influence the representation of concepts. The boundaries of basic categories may not be invulnerable to the effects of language (e.g., Boroditsky, 2001; Gordon, 2004). As one example, Imai and Gentner (1997; see also Imai, 1995) showed that Japanese- and English-speaking children differentially weighted the importance of a similar substance and similar configuration when choosing which item was the same as an example. This issue of how language may lead to differences in categorical structure is potentially very important inasmuch as we learn a large proportion of our concepts through communicating by direct instruction or implicitly through conversation (see Markman and Makin, 1998).

## 2.29.5 Conclusions

In this chapter, we have presented an overview of research on concept and category learning, but we have done so from a particular perspective. Although classification models and experiments have dominated the laboratory work in this area, some recent work has questioned both the focus on classification and its use of simple featural-based items. This work has promoted a broader examination of concept and category learning in three ways. First, a variety of category-learning paradigms are being investigated, along with models that can perform other category functions besides classification. Second, the complexity of the material being learned has increased to include relational categories, prior knowledge, and nonobject categories. New models are also being proposed to begin to account for these complexities. Third, this perspective encourages a consideration of how concept and category learning may be viewed in other areas of cognition. These advances should provide a richer, broader view in the future, so we can better understand the learning of concepts and categories and their crucial role for intelligent thought and action.

## References


Adelson B (1981) Problem solving and the development of abstract categories in programming languages. *Mem. Cognit.* 9: 422–433.

Ahn W (1999) Effect of causal structure on category construction. *Mem. Cognit.* 27: 1008–1023.

Ahn W and Kim NS (2005) The effect of causal theories on mental disorder diagnosis. In: Ahn W, Goldstone R, Love B, Markman A, and Wolff P (eds.) *Categorization Inside and Outside the Laboratory: Festschrift in Honor of Douglas L Medin*, pp. 273–288. Washington, DC: American Psychological Association.

Ahn W and Medin DL (1992) A two-stage model of category construction. *Cognit. Sci.* 16: 81–122.

Ahn W, Marsh JK, Luhmann CC, and Lee K (2002) Effect of theory-based feature correlations on typicality judgments. *Mem. Cognit.* 30: 107–118.

Anderson AL, Ross BH, and Chin-Parker S (2002) A further investigation of category learning by inference. *Mem. Cognit.* 30: 119–128.

Anderson JR (1990) *The Adaptive Character of Thought*. Hillsdale, NJ: Erlbaum.

Anderson JR (1991) The adaptive nature of human categorization. *Psychol. Rev.* 98: 409–429.

Ashby FG and Ennis JM (2006) The role of the basal ganglia in category learning. In: Ross BH (ed.) *The Psychology of Learning and Motivation,* vol. 46, pp. 1–36. San Diego: Academic Press.

Barsalou LW (1985) Ideals, central tendency, and frequency of instantiation as determinants of graded structure in categories. *J. Exp. Psychol. Learn. Mem. Cogn.* 11: 629–654.

Barsalou LW (1990) On the indistinguishability of exemplar memory and abstraction in category representation. In: Srull TK and Wyer RS (eds.) *Advances in Social Cognition, Volume III: Content and Process Specificity in the Effects of Prior Experiences*, pp. 61–88. Hillsdale, NJ: Erlbaum.

Bedard J and Chi MTH (1992) Expertise. *Curr. Direct. Psychol. Sci.* 1: 135–139.

Billman D and Knuston JF (1996) Unsupervised concept learning and value systematicity: A complex whole aids learning the parts. *J. Exp. Pyschol. Learn. Mem. Cognit.* 22: 458–475.

Bloom P (1990) *Semantic Structure and Language Development.* PhD Thesis, Massachusetts Institute of Technology.

Bloom P (1994) Possible names: The role of syntax–semantics mappings in the acquisition of nominals. *Lingua* 92: 297–329.

Bloom P (1996) Possible individuals in language and cognition. *Psychol. Sci.* 5: 90–94.

Bloom P and Kelemen D (1995) Syntactic cues in the acquisition of collective nouns. *Cognition* 56: 1–30.

Bock K and Miller CA (1991) Broken agreement. *Cognit. Psychol.* 23: 45–93.

Boroditsky L (2001) Does language shape thought? Mandarin and English speakers' conceptions of time. *Cognit. Psychol.* 43: 1–22.

Bransford JD and Stein BS (1993) *The Ideal Problem Solver*. New York: WH Freeman.

Brooks LR, Squire-Graydon R, and Wood TJ (2007) Diversion of attention in everyday concept learning: Identification in the service of use. *Mem. Cognit.* 35: 1–14.

Bruner JS, Goodnow JJ, and Austin GA (1956) *A Study of Thinking*. New York: Wiley.

Chase WG and Simon HA (1973) Perception in chess. *Cognit. Psychol.* 4: 55–81.

Chi MTH, Feltovitch P, and Glaser R (1981) Categorization and representation of physics problems by experts and novices. *Cognit. Sci.* 5: 121–152.

Chin-Parker S and Ross BH (2002) The effect of category learning on sensitivity to within-category correlations. *Mem. Cognit.* 30: 353–362.

Chin-Parker S and Ross BH (2004) Diagnosticity and prototypicality in category learning: A comparison of inference learning and classification learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 216–226.

Clapper JP and Bower GH (1994) Category invention in unsupervised learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 443–460.

Clapper JP and Bower GH (2002) Adaptive categorization in unsupervised learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 28: 908–923.

Cummins DD (1992) Role of analogical reasoning in the induction of problem categories. *J. Exp. Psychol. Learn. Mem. Cognit.* 18: 1103–1124.

Eberhard KM, Cutting JC, and Bock K (2005) Making syntax of sense: Number agreement in sentence production. *Psychol. Rev.* 112: 531–559.

Egan DE and Schwartz BJ (1979) Chunking in recall of symbolic drawings. *Mem. Cognit.* 7: 149–159.

Erickson MA and Kruschke JK (1998) Rules and exemplars in category learning. *J. Exp. Psychol. Gen.* 127: 107–140.

Erickson JE, Chin-Parker S, and Ross BH (2005) Inference and classification learning of abstract coherent categories. *J. Exp. Psychol. Learn. Mem. Cogn.* 31: 86–99.

Giralt N and Bloom P (2000) How special are objects? Children's reasoning about objects, parts, and holes. *Psychol. Sci.* 11: 497–501.

Gobet F and Simon HA (2000) Five seconds or sixty? Presentation time in expert memory. *Cognit. Sci.* 24: 651–682.

Goldmeier E (1972) Similarity in visually perceived forms. *Psychol. Issues* 8: 14–135.

Gordon P (2004) Numerical cognition without words: Evidence from Amazonia. *Science* 306: 496–499.

Hampton JA (1993) Prototype models of concept representation. In: Van Mechelen I, Hampton JA, Michalski RS, and Theuns P (eds.) *Categories and Concepts: Theoretical Views and Inductive Data Analysis*, pp. 67–95. San Diego: Academic Press.

Hampton JA (2006) Concepts as prototypes. In: Ross BH (ed.) *The Psychology of Learning and Motivation,* vol. 46, pp. 79–113. San Diego: Academic Press.

Hayes BK and Younger K (2004) Category-use effects in children. *Child Devel.* 75: 1719–1732.

Heit E (1992) Categorization using chains of examples. *Cognit. Psychol.* 24: 341–380.

Heit E and Bott L (2000) Knowledge selection in category learning. In: Medlin DL (ed.) *Psychology of Learning and Motivation,* vol. 39, pp. 163–199. San Diego: Academic Press.

Hummel JE and Holyoak KJ (2003) A symbolic-connectionist theory of relational inference and generalization. *Psychol. Rev.* 110: 220–264.

Hummel JE and Ross BH (2006) Relating category coherence and analogy: Simulating category use with a model of relational reasoning. In: *Proceedings of the Twenty-Eighth Annual Cognitive Science Society*, p. 2647. Hillsdale, NJ: Erlbaum.

Imai M (1995) Constraint on word-learning constraints. *Jpn. Psychol. Res.* 41: 5–20.

Imai M and Gentner D (1997) A cross-linguistic study of early word meaning: Universal ontology and linguistic influence. *Cognition* 62: 169–200.

Jackendoff R (1991) Parts and boundaries. *Cognition* 78: B17–B25.

Johansen MK and Kruschke JK (2005) Category representation for classification and feature inference. *J Exp. Psychol Learn. Mem. Cognit.* 31: 1433–1458.

Kaplan AS and Murphy GL (1999) The acquisition of category structure in unsupervised learning. *Mem. Cognit.* 27: 699–712.

Kaplan AS and Murphy GL (2000) Category learning with minimal prior knowledge. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 829–846.

Kemp C, Tenenbaum JB, Griffiths TL, Yamada T, and Ueda N (2006) Learning systems of concepts with an infinite relational model. Twenty-Fourth National Conference on Artificial Intelligence (AAAI-06), Boston, MA, July 2006.

Kim N and Ahn W (2002) Clinical psychologists' theory-based representations of mental disorders predict their diagnostic reasoning and memory. *J. Exp. Psychol. Gen.* 131: 451–476.

Kruschke JK (1992) ALCOVE: An exemplar-based connectionist model of category learning. *Psychol. Rev.* 99: 22–44.

Larkin J, McDermott J, Simon DP, and Simon HA (1980) Expert and novice performance in solving physics problems. *Science* 208: 1335–1342.

Lassaline ME and Murphy GL (1996) Induction and category coherence. *Psychon. Bull. Rev.* 3: 95–99.

Love BC (2003) The multifaceted nature of unsupervised category learning. *Psychon. Bull. Rev.* 10: 190–197.

Love BC and Gureckis TM (2005) Modeling learning under the influence of culture. In: Ahn WK, Goldstone RL, Love BC, Markman AB, and Wolff P (eds.) *Categorization Inside and Outside the Laboratory: Essays in Honor of Douglas L Medin*, pp. 229–248. Washington, DC: American Psychological Association.

Love BC, Markman AB, and Yamauchi T (2000) Modeling classification and inference learning. *Proceedings of the Fifteenth National Conference on Artificial Intelligence* 15: 136–141.

Love BC, Medin DL, and Gureckis TM (2004) SUSTAIN: A model of human category learning. *Psychol. Rev.* 111: 309–332.

Lynch EB, Coley JD, and Medin DL (2000) Tall is typical: Central tendency, ideal dimensions and graded category structure among tree experts and novices. *Mem. Cognit.* 28: 41–50.

Malt BC, Ross BH, and Murphy GL (1995) Predicting features for members of natural categories when categorization is uncertain. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 646–661.

Markman AB and Makin VS (1998) Referential communication and category acquisition. *J. Exp. Psychol. Gen.* 127: 331–354.

Markman AB and Ross BH (2003) Category use and category learning. *Psychol. Bull.* 129: 592–613.

McRae K (2004) Semantic memory: Some insights from feature-based connectionist attractor networks. In: Ross BH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* Vol. 45, pp. 41–86. San Diego: Academic Press.

Medin DL (1989) Concepts and conceptual structure. *Am. Psychol.* 44: 1469–1481.

Medin DL and Schaffer MM (1978) Context theory of classification. *Psychol. Rev.* 85: 207–238.
Medin DL, Lynch EB, Coley JD, and Atran S (1997) Categorization and reasoning among tree experts: Do all roads lead to Rome? *Cognit. Psychol.* 32: 49–96.
Medin DL, Lynch EB, and Solomon KO (2000) Are there kinds of concepts? *Annu. Rev. Psychol.* 51: 121–147.
Medin DL, Ross N, Atran S, Cox D, Coley J, Proffitt J, and Blok S (2006) Folkbiology of freshwater fish. *Cognition* 99: 237–273.
Middleton EL, Wisniewski EJ, Trindel KA, and Imai M (2004) Separating the chaff from the oats: Evidence for a conceptual distinction between count noun and mass noun aggregates. *J. Mem. Lang.* 50: 371–394.
Minda JP and Ross BH (2004) Learning categories by making predictions: An investigation of indirect category learning. *Mem. Cognit.* 32: 1355–1368.
Minda JP and Smith JD (2001) Prototypes in category learning: The effects of category size, category structure, and stimulus complexity. *J. Exp. Psychol. Learn. Mem. Cognit.* 27: 775–799.
Mufwene S (1984) The count–mass distinction and the English lexicon. In: Testen D, Mishra V, and Drogo J (eds.) *Papers from the Parasession on Lexical Semantics*, pp. 200–221. Chicago: Chicago Linguistic Society.
Murphy GL (2002) *The Big Book of Concepts*. Cambridge, MA: MIT Press.
Murphy GL (2005) The study of concepts inside and outside the laboratory: Medin versus Medin. In: Ahn WK, Goldstone RL, Love BC, Markman AB, and Wolff P (eds.) *Categorization Inside and Outside the Laboratory: Festschrift in Honor of Douglas L Medin*, pp. 197–213. Washington, DC: American Psychological Association.
Murphy GL and Allopenna PD (1994) The locus of knowledge effects in concept learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 904–919.
Murphy GL and Medin DL (1985) The role of theories in conceptual coherence. *Psychol. Rev.* 92: 289–316.
Murphy GL and Ross BH (1994) Predictions from uncertain categorizations. *Cognit. Psychol.* 27: 148–193.
Murphy GL and Ross BH (2005) The two faces of typicality in category-based induction. *Cognition* 95: 175–200.
Murphy GL and Wisniewski EJ (1989) Feature correlations in conceptual representations. In: Tiberghien G (ed.) *Advances in Cognitive Science Vol. 2: Theory and Applications*, pp. 23–45. Chichester: Ellis Horwood.
Newell A and Simon HA (1972) *Human Problem Solving*. New York: Prentice-Hall.
Nosofsky RM (1986) Attention, similarity and the identification-categorization relationship. *J. Exp. Psychol. Gen.* 115: 39–57.
Nosofsky RM (1991) Relation between the rational model and the context model of categorization. *Psychol. Sci.* 2: 416–421.
Nosofsky RM, Palmeri TJ, and McKinley SC (1994) Rule-plus-exception model of classification learning. *Psychol. Rev.* 101: 53–97.
Pazzani MJ (1991) Influence of prior knowledge on concept acquisition: Experimental and computational results. *J. Exp. Psychol. Learn. Mem. Cogn.* 17: 1416–1432.
Pretz JE, Naples AJ, and Sternberg RJ (2003) Recognizing, defining, and representing problems. In: Davidson JE and Sternberg RJ (eds.) *The Psychology of Problem Solving*, pp. 3–30. Cambridge: Cambridge University Press.
Proffitt JB, Coley JD, and Medin DL (2000) Expertise and category-based induction. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 811–828.
Rehder B and Murphy GL (2003) A knowledge-resonance (KRES) model of category learning. *Psychon. Bull. Rev.* 10: 759–784.
Rosch E and Mervis CB (1975) Family resemblances: Studies in the internal structure of categories. *Cognit. Psychol.* 7: 573–605.
Ross BH (1996) Category representations and the effects of interacting with instances. *J. Exp. Psychol. Learn. Mem. Cogn.* 22: 1249–1265.
Ross BH (1997) The use of categories affects classification. *J. Mem. Lang.* 37: 240–267.
Ross BH (1999) Post-classification category use: The effects of learning to use categories after learning to classify. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 743–757.
Ross BH (2000) The effects of category use on learned categories. *Mem. Cognit.* 28: 51–63.
Ross BH and Kennedy PT (1990) Generalizing from the use of earlier examples in problem solving. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 42–55.
Ross BH and Makin VS (1999) Prototype versus exemplar models. In: Sternberg RJ (ed.) *The Nature of Cognition*, pp. 205–241. Cambridge, MA: MIT Press.
Ross BH and Murphy GL (1996) Category-based predictions: Influence of uncertainty and feature associations. *J. Exp. Psychol. Learn. Mem. Cogni.* 22: 736–753.
Ross BH, Gelman SA, and Rosengren KS (2005) Children's category-based inferences affect classification. *Brit. J. Dev. Psychol.* 23: 1–24.
Shepard RN (1962a) Analysis of proximities: Multidimensional scaling with an unknown distance function I. *Psychometrika* 27: 125–140.
Shepard RN (1962b) Analysis of proximities: Multidimensional scaling with an unknown distance function II. *Psychometrika* 27: 219–246.
Silver EA (1979) Student perceptions of relatedness among verbal problems. *J. Res. Math. Educ.* 10: 195–210.
Silver EA (1981) Recall of mathematical problem information: Solving related problems. *J. Res. Math. Educ.* 12: 54–64.
Smith JD and Minda JP (1998) Prototypes in the mist: The early epochs of category learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 24: 1411–1436.
Smith JD and Minda JP (2000) Thirty categorization results in search of a model. *J Exp. Psychology: Learn. Mem. Cognit.* 26: 3–27.
Smith JD and Minda JP (2001) Journey to the center of the category: The dissociation in amnesia between categorization and recognition. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 984–1002.
Soja NN, Carey S, and Spelke S (1991) Ontological categories guide young children's inductions of word meaning: Object terms and substance terms. *Cognition* 38: 179–211.
Solomon KO, Medin DL, and Lynch EB (1999) Concepts do more than categorize. *Trends Cogn. Sci.* 3: 99–105.
Storms G (2004) Exemplar models in the study of natural language concepts. In: Ross BH (ed.) *The Psychology of Learning and Motivation,* Vol. 45, pp. 1–39. San Diego: Academic Press.
Tomlinson MT and Love BC (2006) Learning abstract relations through analogy to concrete exemplars. In: *Proceedings of the Twenty-Eighth Annual Cognitive Science Society*, pp. 2269–2274 Hillsdale, NJ: Erlbaum.
Tversky A (1977) Features of similarity. *Psychol. Rev.* 84: 327–352.
Vigliocco G, Butterworth B, and Garrett MF (1996) Subject-verb agreement in Spanish and English: Differences in the *role* of conceptual constraints. *Cognition* 61: 261–298.
Wattenmaker WD (1992) Relational properties and memory based category construction. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 282–304.
Wattenmaker WD, Dewey GI, Murphy TD, and Medin DL (1986) Linear separability and concept learning: Context, relational properties, and concept naturalness. *Cognit. Psychol.* 18: 158–194.
Wierzbicka A (1988) *The Semantics of Grammar*. Amsterdam: John Benjamins.

Wisniewski EJ and Medin DL (1994) On the interaction of theory and data in concept learning. *Cognit. Sci.* 18: 221–281.

Wisniewski EJ, Imai M, and Casey L (1996) On the equivalence of superordinate concepts. *Cognition* 60: 269–298.

Wisniewski EJ, Lamb CA, and Middleton EL (2003) On the conceptual basis for the count and mass noun distinction. *Lang. Cogn. Process.* 18: 583–624.

Wittgenstein L (1953) *Philosophical Investigations. Anscombe GEM (trans.)*. Malden, MA: Blackwell.

Yamauchi T and Markman AB (1998) Category learning by inference and classification. *J. Mem. Lang.* 39: 124–148.

Yamauchi T and Markman AB (2000) Learning categories composed of varying instances: The effect of classification, inference, and structural alignment. *Mem. Cognit.* 28: 64–78.

# 2.30 Language Learning

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## 2.30.1 Introduction

### 2.30.1.1 What Is Language, and What Makes It a Unique Learning Problem?

Language presents an unparalleled problem for any account of human learning. As adults we have little insight into, or memory of, the learning task we faced during infancy and early childhood. Adult language processing is normally so efficient that we cannot introspect the cognitive or neural processes that accompany such prosaic language-uses as making small talk or listening to a story – processes that include attention-modulation, classification, retrieval, inference, and cognitive control.

By examining language development in infants and children we may gain insight into the challenges, progress, and process of this singularly important and universal learning task. The overall topic is extremely complex, and a thorough treatment would include detailed consideration of phenomena including multilingualism, second-language learning, language loss, aging, developmental disabilities, genetics, and animal learning. Due to space limitations, however, and the intricacies of each of these topics, this overview will focus on the paradigmatic phenomenon of first-language learning by healthy infants and children.

To begin, we must address the thorny question of what makes language a unique modality for social information, and why language acquisition might be a singularly difficult problem for the cognitive and social sciences.

### 2.30.1.2 Why Is Language Hard to Learn?

Human languages (numbering between 3,000 and 8,000, depending on definitions and some unknowns) share some basic features. The world's languages differ in many regards: the set of sound-distinctions that change the meaning of an utterance (or movements that change the meaning of a sign); how meaning-elements can be altered and combined to express complex meanings; what specific meanings are encoded by words (and by derived words, phrases, or idioms); and how various speakers and listeners in a community may use language for different purposes in different situations. Given the stunning variability of the world's languages, effort has been made to identify linguistic universals. The broadest universals are: hierarchical structure (e.g., rules for combining, changing, and deleting/reducing phonemes (speech sounds), morphemes (smallest meaning units), words, and phrases); arbitrariness of form; modifiability of forms (by assimilation, simplification, or metaphor); and combinatorial complexity. Other universals are more specific. For example, despite phonological variability across languages, there is a common ordering by which, for example, vowels are accrued. As another example, all languages can somehow refer differently to *self* versus *other*. Other universals are more like parameters that take one of several 'values,' and these must be learned by children presumably from culture-specific input (as opposed, in the case of 'true' universals, to learning from some universal experiences).

Despite these universals, the profound differences between languages make it hard to specify children's ability to learn language. Children must be prepared to learn language with phonological tone variations (e.g., Mandarin dialects; Yoruba) or percussive 'click' or air-ingestive noises (Sindhi, Xhoso, Zulu), or languages like Hawaiian with very limited phonology. In terms of morphology (i.e., patterns of variation in word structure), children must be prepared to learn languages with limited verb morphology but extensive use of auxiliary verbs, like English, or languages with extensive verb inflections and vowel harmony (i.e., where the root vowel changes the verb's inflections), like Hungarian. Specific examples abound: children learning English must make some verbs reflexive by adding '[possessive pronoun]-self,' whereas children learning Hebrew must learn to affix /hit-/ to most verbs – unless the first sound is a fricative (e.g., /s-/), in which case there is a complex switching of phonemes in the root verb and inflected affix. Mohawk uses a morphological inflection /-atat-/ to indicate reflexive action, but also has a 'semireflexive' morpheme to indicate relatively high involvement or self-generation of an activity. Many more examples can be found in syntax: for example English-speaking children learn that roles (subject, object) are cued by word order; Italian-speaking children must learn to use other cues (e.g., animacy). In semantics, English-speaking toddlers must learn that 'diaper' and 'underwear' refer to things with similar shapes that cover the same body parts but different material and contexts of use, whereas 'hat' and 'gloves' differ in shape and body parts but share material and contexts of use; and 'clothes' refers to all of these but is a mass noun (which usually refer to uncountable things like liquids). Finally, in pragmatics Spanish-speaking children must learn different second-person pronouns for adults and peers; Japanese children must learn different honorifics for men and for women; English-speaking children may say 'you' in all cases.

Thousands of between-language differences like these highlight the complexity of the learning problem faced by children and the difficulty of specifying what children might be prepared to learn *a priori*. Yet even within a language the learning problems are daunting. For example, the regular English past tense inflection is an affix /-ed/ after the main verb. But in fact the phonological form can be /-d/ (e.g., 'bugged'), /-t/ ('marked'), /-ed/ ('blasted'), or /-id/ ('melted'). Moreover, different speakers or dialects use different variants of the same ending, *and* the phoneme before the ending changes the sound of the ending. Thus, in spoken language there is much more variability of form than in writing. Also, there are many irregular past-tense forms: 'run'/'ran' or 'swim'/'swum' (medial vowel change); 'is'/'was' (initial consonant-vowel change); 'go'/'went' (different word), etc. Ignoring the reasons for these differences, from the learner's position most of these are at best only loosely predictable. They must be memorized as exceptions, or inferred from subtle patterns (e.g., verbs ending in /-ing/ ['bring'; 'sing'] have a medial vowel change (/-i-/ to /-u-/).

Children sometimes learn these exceptions early: for example 3-year-olds are sensitive to a constraint on pluralizing the head of a compound noun, which sounds grammatical for irregulars ('mouse-eater' to 'mice-eater') but not regular nouns (e.g., 'rat-eater' to *'rats-eater') (Gordon, 1985). No one teaches children this explicitly, but by age 3 children have begun to learn not only the obvious rules but less-obvious conditional regularities like these. This illustrates children's preparedness to acquire a massive hierarchical system of probabilistic heuristics and exceptions for allowable forms of words, phrases, and sentences. There is much evidence that 2- and 3-year-olds are learning to treat language as an abstract, modifiable, combinatorial system of conventional forms, transformations, and uses (Gordon, 1985; Clark, 1997; Tomasello, 1999; Bates et al., 2003). Yet 3-year-olds still have much to learn. This is a critical point: it is often assumed that children are astoundingly good language-learners despite the intrinsic difficulty of the task. Certainly the task seems difficult, but compared with what? Vision? Motor skills? Such questions are difficult to answer because they require an information-theoretic comparison of different learning problems, and making any such comparison in an even-handed way would be difficult or impossible. Similarly, it is nearly meaningless to claim that children learn language 'quickly.' Compared with what? Learning calculus? Learning to drive? Any such comparison is so problematic that the absurd difficulty of the question becomes obvious. Children require a good five years of steady, ample language input (for hours every day), with massive social and physical support, to achieve fluency. The cost of failure is exclusion from social interaction and information. Stated like this, it becomes hard to defend any assumptions about the specialization of language-learning processes.

To move from fuzzy assumptions toward a clearer understanding of the language learning problem and how children solve it, the following sections summarize what infants learn in the first year, what toddlers learn in the second and third years, what preschoolers learn in the third and fourth years, and what older children continue to learn thereafter. A critical issue throughout is how these changes differ from language to language. It is critical because we want a valid characterization of the universal capacity for language learning. First, though, we address two factors that are part and parcel of that capacity: the ecological context of first-language learning and the relation of language learning to the human genome.

### 2.30.1.3 The Context of Language-Learning 'in the Wild'

Language is used differently in different communities, and this is part of the learning problem for infants. Infants and toddlers are not consciously reflecting on language as a learning 'problem' akin to some monumental homework assignment. Their motives are to affiliate with caregivers, maximize hedonic states and minimize unpleasant ones, predict what other people will do, and join in positive social exchanges whenever a felicitous opportunity arises. Language is an integral part of the events that fit these motives: it is present in all sorts of social events from birth and even before (DeCasper and Fifer, 1980). The point is often forgotten: infants are not *trying* to learn language. They are trying to satisfy dynamic endogenous needs and modulate their affective states. This requires action, reaction, and learning about dynamic social environments. Language is a diffuse category of information that variably (but not randomly) occurs concurrently with social events. Sometimes language information is correlated with ongoing social events and variables, as during one-on-one baby-talk. Other times it is independent of the infant's experience, as when a caregiver chats with another adult while feeding the infant. Thus, an infant's language input is *sometimes* tailored to her ongoing experience. Sometimes it is not.

Thus, to understand how infants and children can acquire any language we must consider in part the range of language-uses in infants' social environments. For example adults modify their speech when speaking to infants, and infants prefer to hear infant-directed speech (Cooper and Aslin, 1990; Pegg et al., 1992). It therefore seems infant-directed speech should facilitate infants' language learning, and in fact it can facilitate adults' learning (Golinkoff and Alioto, 1995). However, there are language communities where adults do not address babies. Still, infants in these communities seem to acquire language at about the same rate as infants who regularly hear infant-directed speech (Lieven, 1994), though they might experience some delays in productive competence (Brown, 1998). Thus infant-directed speech is not a 'hard' prerequisite of learning, although it might accelerate *some* aspects of language acquisition.

The points are that (1) all cultures do not communicate with their infants in similar ways; (2) it is not obvious how different cultural practices influence language learning: we must test these empirically (e.g., Bornstein et al., 1998). Other examples in the following sections show that our intuitions of 'what matters' in language learning often lack empirical support.

### 2.30.1.4 How to Think About Genetic Factors in Language Learning

There is no doubt that language is a species-specific capacity. Some universal language features are not acquired by any other species, however smart their members are in other regards. Specifically, hierarchical structure, modifiability/extensibility of forms, and combinatorial complexity are all absent or profoundly limited in our nearest evolutionary neighbors, the great apes (Terrace et al., 1979; Deacon, 1997). What, then, allows learning in nearly every child in every human community?

Explanations from genetic causes have limited power to explain language outcomes (Braine, 1992; Elman et al., 1996; Karmiloff-Smith, 1998). Certainly language learning requires genetic coregulation of brain development that leads, in a protracted and dynamic cascade of multifactorial changes, to particular information processing phenotypes. Yet that claim is very different from a stronger claim, that some specific evolutionary adaptation(s) were propagated in our ancestors *because they coded for* specialized, species-specific (and adaptive) language phenotypes. That is possible but entirely hypothetical. Nevertheless, strong claims for *specialized* genetic bases of language have been made, buttressed by reference to the well-publicized discovery of a family with many members who have severe language deficits (Gopnik, 1997). Affected family members shared a point mutation (i.e., single-amino-acid substitution) of a gene in chromosome 7 (Lai et al., 2001). The gene, dubbed FOXP2, induces RNA transcription to affect the expression of an indeterminate number of other genes, including some that code for proteins that affect neural structures (e.g., calcium channels). The downstream effects of FOXP2 mutations have been hotly debated. Vargha-Khadem et al. (1998) found differences in several brain regions including Broca's area (left inferior-frontal cortex), which is nonexclusively involved in language production, and caudate nucleus (in the basal ganglia), which is involved in motor coordination and which communicates with frontal cortex. Both changes might explain the profound speech deficits in affected family members. However, those deficits are hardly isolated: affected family members also show generalized motor coordination deficits. Given that language production is an incredibly elaborate feat of motor coordination, one would expect *general* motor problems to manifest as speech deficits. Another finding is that most affected members show mild verbal *and* nonverbal mental retardation. This is not surprising because a transcription factor could have widespread effects on neural development.

Comparative studies further complicate the FOXP2 story. Multiple species – mice, for example – have versions of FOXP2. Mice FOXP2 differs from human FOXP2 by three base changes (i.e., amino acid) (Enard et al., 2002). However, two of these are unique to humans and hypothesized to have evolved in the last 200 000 years. Thus, although FOXP2 interacts with brain development in complex ways to produce many cognitive and behavioral effects, it is possible that recent mutations lead to new hominid neural and cognitive phenotypes that 'tipped the scale' to permit, among other cognitive capacities, language. It is also possible that the correlation is spurious.

In sum, although genes must be related to language learning, researchers have only recently started asking more sophisticated questions about the relations: what role do FOXP2 and other genes play in emergent cascades of neural and neurochemical processes during brain development? How are the neural networks that develop for association learning, perceptual-motor learning, and social-information processing altered by the coactivation of mutated gene forms? Such questions are central to our eventual understanding of language abilities and their expression as developmental products. However, current answers to these questions are almost pure speculation.

### 2.30.1.5 Are There Critical Periods for Learning?

There is a popular idea that language fluency can be attained only during a limited window of age, after which brain plasticity becomes reduced and fluency is difficult or impossible to achieve (Lenneberg, 1967). This is consistent with evidence of partial reduction in plasticity with age (Stiles, 2000) and with computational models wherein early input patterns have a greater effect on learned network weights than later input patterns (i.e., 'starting small'; Elman, 1993; Smith et al., 2001).

Most evidence for a critical period in language learning comes from studies relating L2 (second-language) competency to age-of-acquisition, controlling for years of exposure. (Critical periods in phoneme discrimination are discussed in the section titled ‘Classification problem: speech sounds in the infant’s sound-scape.’) Johnson and Newport (1989), for example, tested adult Korean and Chinese immigrants on English syntactic distinctions. They found a linear decline in competence with increasing age of acquisition, from 8 to 39 years, but no difference in starting ages ranging from 3 to 7 years. This suggests a gradual, continuous decline from about 7 years to adulthood in the capacity to master syntactic details of a new language.

Subsequent studies have shown that it is difficult to predict what syntactic competencies will be compromised by missing early experience. Mayberry and Lock (2003) compared adult English-speakers to adults who learned English in late childhood after learning (1) a signed language, or (2) a non-English spoken language, or (3) no language (as profoundly deaf infants in speaking family). Non-language learners were impaired in processing all sentence types, including simple ones. Early signers or non-English speakers were compromised only in processing complex or noncanonical sentences, especially dative alternations (“The father gave a boy a dog”) and relative clauses (“The boy who is chasing the girl is happy”), both of which can be considered generally difficult English syntactic structures. However, performance on complex sentences did not differ between the latter groups, suggesting that modality of first language has little effect on what forms are easier or harder to learn in L2.

Despite such converging evidence for critical period effects in articulation and syntax, the exact nature and cause remain controversial. Many studies do not document or factor out the learning conditions of immigrants of different ages, but these conditions are quite important: child immigrants are often immersed in school, whereas adults might spend time with other L1-speaking adults and receive far less L2 input (Stevens, 1999). In fact, some researchers argue there is little or no compelling evidence of critical periods for language (Birdsong, 1992; Flege, 1999). For example, a study of U.S. census data from a large sample of Spanish- and Chinese-speaking adults found that educational attainment (in U.S. schools) accounted for more variance in self-reported English fluency (26% and 42%, respectively) than age of arrival (6% and 9%, respectively) (Hakuta et al., 2003). Notably, the modest (<10% of variance) schooling-independent effect of age showed no inflection during a particular age range: the function was nearly linear, indicating no discrete cutoff in learning capacity associated with, e.g., puberty. However, Stevens (1999) also used census data and found subtle nonlinearities when regressing the probability of immigrants responding that they speak English ‘very well’ or ‘well’ against age of immigration, with the greatest change between 1 and 7 years of age. However, because census methods have limited sensitivity and validity, and because behavioral evidence shows no age range during which L2 learning rapidly declines (Johnson and Newport, 1989), we tentatively conclude that there is no narrow period of development (i.e., 1–3 years) during which language learning becomes crystallized or limited. Future research could tackle intriguing questions, such as why some adults learn L2 and achieve complete fluency, but others learn L2 during adolescence and never approach fluency.

### 2.30.1.6 Summary

The past two decades have shed considerable light on some *general* questions about the human capacity to learn language. From comparative studies we have learned that, although some nonhuman animals can learn and use up to a few hundred abstract symbols and respond correctly to short, simple, concrete sentences (Savage-Rumbaugh et al., 1993), there is no evidence they can flexibly and productively use symbols for a wide range of meanings (e.g., abstract/nonphysical concepts) or truly flexible syntactic structures, not to mention morphology. Nor do nonhuman animals show prosaic language uses like word play, commenting on absent referents, metaphor, humor, or nonliteral speech.

It seems clear that there is no precipitous critical period for learning, although there is some evidence for a gradual decline in the probability of mastering subtle phonological and syntactic distinctions of a new language, over starting ages ranging from about age 7 years to adulthood.

Finally, recent studies of language change provide fascinating insight into children’s role in language evolution (i.e., creolization): specifically in systematizing language structures (Senghas and Coppola, 2001; Senghas et al., 2004). For example, creole-signing children spontaneously create syntactic distinctions that mirror distinctions in natural languages (e.g., manner vs. path of motion), whereas those children may conflate manner and path of motion in their nonlinguistic gestures (indicating that the distinction is not *obligatory* but specially formalized in the new language). Other studies indicate that the SVO (subject-verb-object) word order canonical in English, for example, is not a 'natural' order: new signers may create an SOV sign order (Sandler et al., 2005).

Keeping in mind these concerns and conclusions about the learning environment and the genome in first-language learning, we now describe critical findings about how children acquire fluency. The results are organized by age divisions that are roughly defined by changing age-related learning tasks and social contexts. Despite this organization, much of language learning will be ongoing and continuous rather than stage-like. In all that follows, it can be assumed that a developmentally constant demand is to understand what other people are trying to communicate, and master enough abstract language forms to interpret others' meanings and to produce one's own messages such that one's intentions and perspectives can be inferred by others. It should also be assumed, despite some organization into distinct sections, that children do not learn separate aspects of language (syntax vs. morphology vs. pragmatics), rather that these theory-laden and historical distinctions are typically interrelated in human language processing data (Bates et al., 2003).

## 2.30.2 What Is Learned in the First Year

### 2.30.2.1 Classification Problem: Speech Sounds in the Infant's Soundscape

Languages do not use all the same speech sounds. Adult speakers of language X cannot always pronounce, or even discriminate, some phonemes of language Y. For example English voiced bilabial consonants form two phonemes, [b] and [p], that differ only in voice onset time (VOT, or the time between onset of vocal cord vibrations and air release). By contrast, in Thai the same spectrum is divided into three phonemes. English-speaking adults perceive the VOT spectrum as two discrete categories, with a high-entropy region around the /b/–/p/ distinction, but do not perceive a third category in the region of the added Thai contrast. How, if adult speakers cannot even perceive all phonemes, do infants learn whatever complement of speech-sound distinctions is relevant in their language?

During the third trimester of gestation the fetal auditory system is sufficiently developed to begin learning some abstract properties of speech sounds produced by the mother. Although the amniotic sac filters the acoustic content of speech, enough invariants are retained in this filtered signal that, after birth, neonates prefer the sound of their mother's voice (DeCasper and Fifer, 1980). Neonates also perceive some phonetic distinctions such as the /b/–/p/ VOT contrast (Eimas et al., 1971). This suggests that the extensive and well-demonstrated plasticity of auditory cortex (Ohl and Scheich, 2005), which begins prenatally, responds in humans to acoustic invariants of speech.

During the first few months infants become sensitive to differences between phonemes (consonants and vowels), including differences in place of articulation and VOT (Trehub, 1973; Eimas, 1974). Phoneme perception develops such that by 9–12 months infants are sensitive to native contrasts but less sensitive to nonnative contrasts (Werker and Tees, 1999). Werker and Tees (1984) found a decline from 6 to 12 months in English-learning infants' discrimination of a Hindi /Ta/–/ta/ contrast and a Nthlakampx /k'i/–/q'i/ contrast (defined by place of articulation). These distinctions (unlike, e.g., /ba/–/da/) are also subtle for nonnative adults (Werker and Tees, 1999), but can be learned with practice (McClelland et al., 2002). This suggests a sensitive period in phonological development. Phonological processing difficulties for L2 distinctions might, in some cases, lead to larger difficulties with speech processing that resemble L1 language delays (Tallal, 2004).

Despite evidence for a sensitive period in phonological development during the first year, adaptation of the auditory system to language-specific input begins well before 9–12 months. Within their first few days infants discriminate native (French) from foreign (Russian) speech (Mehler and Cristophe, 1994), though discrimination depends partly on how phonologically different the languages are (Nazzi et al., 1998). Whatever neurological changes accompany 9- to 12-month-olds' loss of sensitivity to nonnative contrasts, it is not the case that younger infants are insensitive to native speech features.

#### 2.30.2.1.1 *What categories are infants prepared to learn? Insights from signed languages*

To gain insight into what is distinctive about learning to perceive speech, we can consider how infants learning signed languages acquire the basic linguistic units, that is, motor forms including hand shapes, manual motions, and other body motions (e.g., facial gestures). In what ways, if any, has brain development evolved to favor processing and learning of speech sounds over other modalities?

It is not clear that language learning is at all specialized for speech. Petitto and Marentette (1991) argued that deaf children learning signed languages begin manual 'babbling' by 10 months or earlier. The emergence of a production distinction between signing and gesturing suggests prior perceptual analysis of hand morphology of signs. How young can infants perceive differences in hand shape that carry meaning differences in a signed language? Schley (1991) found 3-month-olds could discriminate at least one hand-shape difference. Though this is not conclusive it suggests there is no great delay in perceptual learning of language-relevant forms in nonspeech modalities. Further, Baker et al. (2006) suggest a critical period in acquiring hand-shape phonology: hearing infants at 4 months classified same- from different-shape tokens (from ASL); 14-month-olds did not. The timing of this loss of sensitivity is roughly similar to loss of nonnative speech sound sensitivity (Werker and Tees, 1999) and is further supported by evidence that older infants learning spoken language lose the tendency to interpret novel gestures as symbolic (Namy and Waxman, 1998).

### 2.30.2.2 Beyond Phonology: Finding the Words

When do infants begin to perceive larger units – specifically, combinations of speech sounds that we hear as words and phrases? This has been a major topic of research in the past decade. For example Jusczyk et al. (1993) found that infants around 7 months discriminate (and prefer) the stress pattern of their native language (e.g., strong-weak in English, e.g., 'mother'; 'bottle'). This preference could help infants parse words in the speech stream; a critical ability because there are no clear acoustic markers of the boundaries of words. How else might infants learn to separate words and inflections in the ongoing speech stream?

Another source of word-boundary information is the likelihood that two phonemes will occur in sequence within some word in a given language. Consider the phrase 'pretty baby,' which has a word boundary between /-y/ and /b-/ but, for all the infant knows, might be three words (e.g., 'pritt ebay bee'). However, the probability of the phoneme sequence 'eeb' in English is much less than the probability of 'tee' or 'bay,' so the former parsing is more likely. Infants can learn such differences in transitional probabilities within minutes, simply by listening to an artificial language with controlled transitional probabilities (Saffran et al., 1996). Thus, before their first birthday infants encode cues to the structure of words. These learning abilities are not specific to word-learning nor to humans: infants can learn analogous transitional probabilities in musical motifs (Saffran et al., 1999) or sequences of visual shapes (Kirkham et al., 2002). Also, tamarin monkeys can learn transitional probabilities in speech phonemes (Hauser et al., 2001). Thus, however important the phoneme-sequence-learning capacity is, it is not sufficient for human speech processing. Also, infants might learn words spoken in isolation faster than embedded words (Brent and Siskind, 2001), suggesting that word segmentation is, despite sequence-learning abilities, resource demanding and/or error prone.

### 2.30.2.3 First Words: Content and Conditions of Learning

#### *2.30.2.3.1 What do infants know about words?*

Deciphering the speech stream involves more than segmenting individual words: children need to associate certain sequences of phonemes with contexts of use or kinds of referents. How do infants learn word meanings? Infants by 4 months attend more to the sound of their own name than another name with the same stress pattern (Mandel et al., 1995). By 7 months such preferences extend to high-frequency words (e.g., 'cup'; Jusczyk and Aslin, 1995). By 11 months infants represent the phonological details of familiar words (Swingley, 2005). How readily do infants learn such representations? Eight-month-olds, after hearing a word several times, discriminated it from other words as long as two weeks later (Jusczyk and Hohne, 1997).

It seems infants can learn and remember sounds of specific words several months before they start using them productively. However, increased attention to familiar patterns is not the same thing as symbolic understanding. When do infants learn to associate words with object types, people, events, or properties? At 8 months infants show a slight tendency to associate an object that was recently paired several times with a novel word, but only if the speaker moved the object in synchrony with saying the word (Gogate and Bahrick, 1998, 2001). The importance of intermodal synchrony underscores the fragility of infants' word-referent associative learning. By 11–14 months, infants are sometimes above chance at attending to an object previously paired with a novel word 6 to 9 times (Woodward et al., 1994). However, it is unclear how much (or little) input is needed for various referents or situations, and whether infants learn anything beyond a weak intermodal association (Shafer and Plunkett, 1998). In other words, we still do not know when and how infants learn words as abstract symbols.

In interpreting all this literature a caveat is in order: much older preschoolers are sometimes insensitive to gross word-form violations (Barton, 1980), suggesting that phonological/lexical knowledge may remain immature long after infancy. The confusing range of sensitivity and insensitivity shown in various studies of infants and preschoolers (e.g., Fisher et al., 2004) demands more sophisticated models than currently exist. One issue is that infants are very sensitive to contextual factors (Naigles, 2002), so the exact conditions of input *and* of testing must be meticulously detailed and compared in order to make sense of different studies of infants' word-form knowledge.

### 2.30.2.4 Beyond Words: Learning Phrase Structure and Lexical-Syntactic Categories

Infants show some awareness of other linguistic patterns in the first year. Fernald and Mazzie (1991) showed that infants are sensitive to prosodic (i.e., melodic) contours of infant-directed utterances that correspond with different messages or meanings (e.g., approval vs. prohibition). Interestingly, prosodic patterns show some consistency across languages (Fernald et al., 1989; Grieser and Kuhl, 1998), suggesting that many societies come to exploit prosodic distinctions that are salient to infants, as a way to draw attention to distinct messages before infants can comprehend specific words or phrases.

Prosodic information might also help infants learn syntactic distinctions. Adults detect phrase and clause boundaries based on speech cues (intonation, stress, pauses, word duration), even when listening to a foreign language (Pilon, 1981). Although these cues are sometimes unpredictable or misleading, they may be more predictable in infant-directed speech (Stern et al., 1983). Several studies (e.g., Hirsh-Pasek et al., 1987; Jusczyk, 1997) indicate that 8- to 10-month-olds expect pauses at syntax-relevant clause and phrase boundaries. This preference is not specific to spoken language; infants also prefer pauses at phrase boundaries in classical music (Krumhansl and Jusczyk, 1990). Also, although prosodic structure could highlight syntactic structure in languages with strong word-order cues (e.g., English) it might be less useful in languages where syntax is carried by inflections (e.g., Hungarian; Icelandic). Still, English-learning infants as young as 2 months can use prosodic clause cues to represent two-word sequences, at least briefly (Mandel et al., 1996).

Infants in the first year might distinguish between kinds of words that correspond to different syntactic categories. Shi and Werker (2003) found 6-month-olds discriminate so-called content ('open-class') words (e.g., 'chair,' 'hide') from grammatical ('closed-class') words ('the,' 'you'), and prefer the former, even in a foreign language. No common phonological cue differentiates these word classes across languages, but some combination of cues is probabilistically available in any language (Morgan et al., 1996). The implication is that languages evolve a lexical 'division of labor *and* form,' so content words have more distinctive phonology than syntactic units. This might contribute to a developmental shift in the kinds of words infants learn as they populate their lexicon and acquire syntax (see the section titled 'New math: populating the lexicon').

It is not just that infants associate more interesting-sounding words with open-class units; they also learn sequences of words. Gómez and Gerken (2000) found that 12-month-olds developed expectations for order and repetition dependencies in small sets of artificial CVC words (e.g., 'pel' can start a sentence *or* follow 'vot'). After training, infants heard novel 'sentences' that were 'grammatical' or 'agrammatical' and listened longer to agrammatical sentences. Thus infants are sensitive to the same types of transitional probabilities between words that Saffran et al. (1996) showed for phonemes. This might support syntax learning.

This finding (see also Marcus et al., 1999) does not show that 12-month-olds have learned syntax, but that they are minimally sensitive to more- versus less-likely orderings of syllables or lexemes, given well-controlled input. Yet syntax involves more than order, and more than just CVC syllables. It involves a number of abstract categories or form classes, systematically related in various ways to other categories, under a system of complex principles and probabilities for changing and combining units. Currently we only know that infants discriminate (1) familiar from less-familiar orderings of syllables; (2) acoustic and prosodic cues that correlate with phrase and clause boundaries; and (3) phonological cues that differentiate broad syntactic categories (e.g., content vs. grammatical words). It remains unknown how this learning contributes to later syntactic knowledge in the next several years.

#### 2.30.2.5 First Uses: Reasons to Learn Language

Recall that, although language researchers describe infants as trying to solve a taxonomy of massively complicated mapping problems, that description is imposed upon the infant whose goals are to stay regulated, reduce uncertainty, and maximize hedonic states. Caregivers who help infants meet these goals sometimes emit streams of vocal noises (or gestures). Why should infants learn these? One reason must be that infants are motivated to affiliate with people, and interested in what people say. Infants must pick and choose information in rich environments. Some human features, such as faces (Fantz, 1963), voices (DeCasper and Fifer, 1980), and hands (Deák et al., 2006) tend to attract infants' attention. If caregivers also talk about their actions while infants are watching them, it can give infants good input for learning words. Hart and Risley (1995) showed that language input – amount and variability of speech – predicts infants' language skills into preschool. Similarly, Tamis-LeMonda et al. (2001) found maternal responsiveness (i.e., reacting quickly and appropriately to the infant's signals) at 9 and 13 months predicted language outcomes including age at first words and acquisition of 50 words. Notably, mothers' responses to infants' vocalizations and play prompts (e.g., acting on a toy while commenting) were the best predictors of language outcomes.

#### 2.30.2.6 Using Social Inferences to Bootstrap Learning

A major shift in our understanding of child language was sparked by evidence that early language is interwoven with intentionality (i.e., awareness of other people's mental states and emotions). Although this awareness becomes more precise and explicit through childhood, its first measurable signs emerge around 9–18 months of age.

Much research has focused on attention-sharing, periods when two or more individuals shift attention to a common focus. Such episodes facilitate communication, because the topic of conversation can be highlighted by extra-linguistic behavior (i.e., if interlocutors comment on whatever has their attention, and both are focused on the same thing, they will tend to share topic). Research and theory of the development of attention-sharing skills in infants, and its relation to language development, is reviewed by Baldwin and Moses (2001), Deák and Triesch (2006), and Tomasello (1999). In short, infants sometimes follow an adult's gaze or pointing gesture by 12 months of age, though the ability improves from 9 to 18 months (Butterworth and Jarrett, 1991; Deák et al., 2000; Brooks and Meltzoff, 2002). Infants might be either more likely to do so, or do so for longer, if the parent verbally encourages them to follow (Flom and Pick, 2003). Thus, parents' speech acts initially have an attention-modulating function for infants.

Does sharing attention conversely facilitate language development? There is no evidence of this in the first year, but early attention-sharing skills seem to support rather sophisticated inferences in the second year (see the section titled 'Inferring the meaning behind the words').

### 2.30.3 What Is Learned in the Second Year

During the second year toddlers' language will advance in several critical ways. Some burgeoning sensitivities of infants become active. Research points to advances in three major areas: lexical knowledge, pragmatics, and syntax. These areas are tightly related, but because research often treats them separately, the following section treats them (artificially) as separate.

#### 2.30.3.1 New Math: Populating the Lexicon

There has been controversy about what kinds of words toddlers first understand. The first 50 words typically include many generic object labels ('bottle'), proper names ('Lara,' 'mommy'), words for actions or modifiers ('up,' 'more'), and social routine words ('bye bye') (Nelson, 1973). One debate is whether first words are highly context restricted or under extended and, therefore, limited in abstraction. Snyder et al. (1981) found about half of 13-month-olds' first 50 words were in fact contextually restricted; yet some should be by definition (e.g., 'bye-bye,' 'peek-a-boo'). Huttenlocher and Smiley (1987) found infants rarely use labels in contextually idiosyncratic ways. Toddlers know so much less than adults about the referent categories of words that their semantic representations must be limited or distorted. Yet one study hints at fairly rapid corrections. Woodward et al. (1994) found 18-month-olds better than 13-month-olds at extending a novel word to a new exemplar like the training object. Thus, toddlers quickly learn to generalize generic words from first (idiosyncratic) referents to abstract classes and thereby reduce contextually restricted uses.

Once toddlers extend words taxonomically, they must still adjust the boundaries of the referent category. Toddlers sometimes overextend words (e.g., use 'ball' for all spheres; Rescorla, 1980) or underextend them (e.g., excluding penguins from 'bird'). Yet such errors do not indicate an inability to map words onto sensible categories. Most overextensions, for example, are based on spurious perceptual or functional similarities (Clark, 1973; Nelson, 1979). Also, there is no evidence that toddlers *typically* over- or underextend words. Many overextensions have a pragmatic basis and do not reflect systemic conceptual confusion (Thompson and Chapman, 1977). That is, when a 1-year-old calls a stranger 'daddy' she is probably not questioning her own legitimacy, but noticing some similarities between a novel referent (strange man) and a familiar one (daddy). Given the child's many lexical gaps, such remote similarities might constitute the only basis for choosing a rarified 'known' word to indicate the referent.

As children receive input they will modify the boundaries of word-meanings using factors such as typicality (White, 1982; Wales et al., 1983). However, we do not know which input factors alter these boundaries, or how.

Despite these early challenges, toddlers make rapid progress in populating their lexicons. One story is that after children learn 50–75 words their rate of word learning accelerates: the 'naming explosion.' This suggests that, after learning some symbolic mappings, toddlers achieve insight about the abstract meanings of words. We do not, in fact, know what higher-order realizations or inferences, if any, facilitate 1-year-olds' word-learning ability. Here, however, are some relevant facts.

First, 1-year-olds tend to interpret others' actions as symbolic. These include gestures as well as words (Namy and Waxman, 1998; Childers and Tomasello, 2002, 2003), so the acceleration is not strictly based on some insight about word-like sound strings. Second, many infants accelerate in word learning around 50–75 words, but others do not (Fenson et al., 1994). Thus, individual infants differ in word-learning trajectory, for reasons that remain unclear despite decades of attempted explanations (e.g., Nelson, 1979).

One hypothesized explanation is that an acceleration in word learning is related to new classification skills (Gopnik and Meltzoff, 1992). Evidence is suggestive but inconclusive. Another idea is that as children learn more words they develop more robust connections among the word representations in neural networks. As the neural representation patterns (i.e., vectors) evoked by particular words become more stable and better defined, this stability can make it easier to learn new word-referent associations (Plunkett et al., 1992; Gasser and Smith, 1998). For example, as children learn words they learn how certain word types (e.g., object labels) are associated with certain referent features (e.g., shape and material), and this can guide inferences about new word meanings (Smith et al., 2003). Thus, increasing semantic knowledge supports new word learning. This is an important principle of word learning throughout childhood and adolescence (Anglin, 1993; Deák, 2000b).

The acceleration in 1-year-olds' word learning is not uniform across kinds of words. An important finding (Fenson et al., 1994; Bates and Goodman, 1999) is that nouns dominate infants' first 50–100 words; however, relational words (i.e., verbs and adjectives) are thereafter learned relatively faster, and become a relatively larger proportion of new vocabulary. Another shift occurs after toddlers know about 300–500 words; learning of grammatical words and morphemes then accelerates. An exciting finding is that this pattern holds (in broad strokes at least) across at least a few Indo-European languages including Italian (Caselli et al., 1999; Devescovi et al., 2005), which differs from English in syntax. There are language-specific differences in vocabulary growth trends, but the relation between vocabulary growth and acceleration of relational words (first) and grammatical words (second) appears robust.

#### 2.30.3.2 Inferring the Meaning Behind the Words

In the second and third years the attentiveness that even younger infants show toward other people, especially in propensity to share attention and monitor others' emotions, becomes more sophisticated and interwoven with language. For example toddlers can use nonlinguistic social cues to reduce uncertainty of a speaker's referential meaning. Baldwin (1995) found 18-month-olds map a novel word onto whatever the speaker was attending to, not what the infant was attending to, even if they were attending to different things. Toddlers do even more sophisticated tracking and encoding of social cues accompanying others' speech acts. Akhtar et al. (1996) had 2-year-olds and two adults looking at objects in boxes. All participants looked at three objects, and then one adult left the room. The remaining adult then examined the fourth object, and the absent adult then returned, looked in the box and said, "... I see a gazzer in there!" Toddlers tended to associate 'gazzer' with the fourth object, though the returning adult never had picked it up, and the adult who picked it up had never said the word. From this it seems toddlers can infer the most plausible referent of a particular speaker's comment or label. Although this finding has invited competing explanations, converging evidence (Diesendruck et al., 2004) shows that 2-year-olds do in fact use social information (e.g., who was present when some referent was the focus of attention, the speaker's emotion while examining an object or performing an action, etc.) to associate words with referents. Toddlers also modify their own communicative behaviors to take into account an interlocutor's social knowledge (O'Neill, 1996), suggesting that they use information related to other people's mental states or knowledge in order to use and learn language effectively.

We cannot tell how reliably and accurately toddlers use social information to guide inferences about speakers' meanings. All studies are done in simplified, controlled 'best-case' environments, whereas the complex, messy world of everyday social interactions might be too variable to help toddlers make inferences. There are, however, two reasons to believe they can. First, young children with autism typically have profound deficits in joint attention and social inference skills and typically very delayed language skills in childhood and adulthood (Loveland and Landry, 1986; Mundy et al., 1990). Thus, infants who do not make use of social information have impaired language development (this is just correlational, but consistent with the hypothesis above). Second, there is naturalistic evidence that parents constrain the social context of their spontaneous communications with toddlers in somewhat predictable ways (Ninio and Snow, 1996; Pan et al., 1996). Thus, the messiness and unpredictability of everyday interactions is partly limited by parents.

#### 2.30.3.3 Combinatorial Explosion: Putting Words Together

The robust relation between vocabulary growth and acquisition of relational and syntactic words (or morphemes) extends to toddlers' syntactic competence (Bates and Goodman, 1999; Devescovi et al., 2005). Apparently toddlers need a 'critical mass' of words for objects, relations, events and states before they can assemble these units productively. Besides this regularity, how does early syntactic expression and comprehension develop in the second year?

Much work has focused on toddlers' two-word utterances. Early combinations are produced with regularity about the same time as the 50–75 word threshold, or 18–24 months. In four children studied by Bloom et al. (1975) an MLU (mean length of utterances, in morphemes) of 1.5 or better (e.g., about half of utterances having two words) was achieved around 22–24 months. Toddlers' first 2-word productions are described as 'telegraphic' because they lack grammatical words and inflections. Nonetheless, they express a variety of relations including action ('Kathryn jumps'), locative action ('tape on there'), locative state ('I sitting'), static state ('Caroline sick'), recurrence ('more milk'), possession ('Mommy sock') and others (e.g., negation) (Bloom et al., 1975). Some types of relations (e.g., action) are systematically verbalized before others (e.g., locative state), even across languages (Braine, 1976). It is unclear whether this is due to conceptual, syntactic, or motivation factors. However, 1-year-olds show some sensitivity to input in the relational meanings they learn. Choi et al. (1999) found differences in Korean and English toddlers' acquisition of spatial predicates such that Korean toddlers are more attentive to spatial relations (e.g., tight- vs. loose-fitting containment) with distinct words in Korean.

A key issue concerns the early emergence of syntactic categories in two-word utterances (Bloom et al., 1975). Such utterances are usually syntactically (and semantically) ambiguous: does 'Mommy sock' denote possession, action (e.g., putting-on), spatial contiguity, or something else? Syntax might help us disambiguate these alternatives, but are there incipient syntactic categories in toddlers' first combinations? Bloom et al. examined subjects' ordering of morphemes and substitutions (e.g., saying 'her jumps' and 'Kathryn jumps'). Such pronominal constructions suggest an intermediate step toward abstract categories like 'subject'. Two of four children were extensive pronoun users, suggesting proto-syntactic classes, but the individual differences makes interpretation difficult (see also MacWhinney, 1978, for evidence on early diversity of morphosyntactic development). Valian (1986) later showed, however, young 2-year-olds' productions of several form classes (noun, determiner, adjective, preposition, noun phrase, and prepositional phrase) to be well differentiated. Also, two-word speakers understand fully formed sentences better than telegraphic ones (Shipley et al., 1969). Thus, 2-year-olds know more about the correct syntax of individual words than it seems from the combinations they produce, and even 1-year-olds might have some rudimentary expectations (e.g., associating the first noun in a sentence with an actor; Hirsh-Pasek and Golinkoff, 1996). A critical question is how infants and toddlers acquire this knowledge. This has been controversial (Braine, 1976; Maratsos and Chalkley, 1980; Bates and MacWhinney, 1982; Pinker, 1984; Tomasello, 1992), and an adequate treatment is impossible due to space limitations. Nevertheless we will provide a historical synopsis.

Maratsos and Chalkley (1980) proposed that toddlers register long-term patterns of co-occurrence in use (and non-use) of words in particular patterns or contexts, in order to eventually learn syntactic frames. This theory, a precursor of connectionist models and early alternative to a Chomskian learning acquisition device (a mythical organ by which language input is assimilated to an innate syntax), offered a plausible means of incremental input-dependent learning. This type of account and its limits are insightfully critiqued by Maratsos (1998).

For a flavor of the history of this sort of 'nativist versus empiricist' debate, consider the controversy over children's acquisition of transformations over rules-with-exceptions. The test case is English past-tense verb forms, with a regular /t/ or /d/ suffix, but various exceptions including vowel change ('come'/'came'), consonant change ('make'/'made'), word change ('go'/'went'), or no change ('cut'/'cut'). Such messiness is hardly unique to English past-tense: English plural nouns have the same property, as do, for example, German gender categories and many other syntactic forms in many languages. The question is how children can acquire diverse forms for the same type of transformation. A relevant finding is that toddlers sometimes overregularize, producing forms like 'goed,' 'runned,' or 'breaked' (not 'went,' 'ran,' or 'broke'). Notably, such forms are often not the earliest produced; toddlers sometimes produce 'went,' then 'goed' for a while, then ultimately the correct irregular (Cazden, 1968). This right-wrong-right progression intrigues linguists because it suggests a progression from individual word-forms to a syntactic rule to rule-with-exceptions. Marcus et al. (1992) found that past-tense overregularizations are infrequent but variable across time and child, and the right-wrong-right pattern is an idealization with high variability. Also, individual overregularization rates correlate with the frequency of irregulars in the child's lexicon and linguistic environment.

How can we explain the variability of these errors across time and child of these errors? Marcus et al. (1992) argued that exceptions must become strong enough as memory traces to be retrieved before the rule is applied. This idea is only partly explanatory, but it leaves open the possibility of fleshing out the account by testing simulations of learning in artificial neural networks (ANNs). Despite early (and often spurious) objections to this approach, it is clear that many complex patterns, including overregularizations, can be modeled by ANNs (Plunkett, 1992; Hadley et al., 1998; Morris et al., 2000; Lewis and Elman, 2001). For example, a syntactic distinction considered by Chomskian theorists to be unlearnable (under 'Poverty of the Stimulus' arguments; see Pullem and Scholz, 2002, for critique) was shown by Lewis and Elman (2001) to be learned by a fairly simple ANN taking training input from natural speech samples.

Toddlers' syntactic knowledge can also be tested in experimental paradigms. For example Akhtar and Tomasello (1997) show that 3-year-olds, but not 2-year-olds, readily induce, from just a few instances, whether a novel word is transitive or intransitive. Although 2-year-olds learned that novel words referred to actions, they did not appropriately generalize their transitive or intransitive status. (Naigles, 2002, offers another interpretation.) Moreover, toddlers will accept and interpret agrammatical uses of familiar verbs (*"The zebra goes the lion") in ways that suggest fluid phrase/frame structure representations (Naigles et al., 1992). In short, although toddlers are starting to learn the syntactic properties of different words and phrases, their specific knowledge is variable, ephemeral, and unorganized by abstract distinctions such as transitive/intransitive.

## 2.30.4 What Is Learned in the Third and Fourth Years

### 2.30.4.1 Acquiring Semantic Relations

As children's vocabulary grows beyond a certain size they must work out a variety of semantic relations, such as inclusion, overlap, and exclusion. For example, are all pets animals? Could any puppy be an herbivore? Deák and Maratsos (1998) showed that 3-year-olds readily produce different labels for an item, and these respect the same semantic relations that adults recognize: if asked about a dog puppet, "Is it a cat?" children reply, "No, it's a dog!". If asked "Is it a doll?" they reply "No, it's a puppet!". The near-errorless pattern of rejections and same-category substitutions suggests that 3-year-olds – and perhaps 2-year-olds (Clark and Svaib, 1997) – represent semantic relations. As early as children know enough words to begin filling in semantic frameworks, they can constrain inferences and naming decisions.

What about adding new words to semantic frameworks? Even 2-year-olds try to make reasonable interpretations of novel words with respect to other words they know, how the word was used, and properties of the referent (Waxman and Senghas, 1992). For example preschoolers can use contrast to interpret new words (Au and Glusman, 1990): if they hear something described "not the red one, but the chromium one," they infer that 'chromium' names an unfamiliar color. Contrary to some claims (Markman and Wachtel, 1992), 2- to 5-year-olds do not by default assume that each word refers to a mutually exclusive category (Waxman and Senghas, 1992; Mervis et al., 1994; Savage and Au, 1996; Deák and Maratsos, 1998; Deák et al., 2001). However, under circumstances like high working-memory load, preschoolers may adopt a temporary mutual exclusivity approach (Liittschwager and Markman, 1994), possibly to simplify the learning task (Deák, 2000a; Deák and Wagner, 2003).

How do preschoolers eventually learn appropriate semantic relations? First, speakers sometimes couch words in meaningful information, like statements of contrast (Au and Glusman, 1990; Callanan, 1990); however, such information is not always enough (Deák and Wagner, 2003) and is more useful to older children (Smith, 1979). Second, syntactic context is sometimes helpful (Naigles, 1990), though for many words in many languages it is a very weak cue. Third, children sometimes analogize from familiar morphological (Anglin, 1993) and semantic (Johnson et al., 1997) relations, but the limits on such analogizing are not known. In short, we usually do not know how preschoolers situate a new word in an existing semantic framework.

### 2.30.4.2 New Uses of Language

Preschool children's language skills develop in the service of social knowledge and interaction. Different language communities value different linguistic skills (Heath, 1983), and 3- and 4-year-olds are improving at using language for different purposes (i.e., genres such as narrative, conversation, or teasing), in different contexts (e.g., home vs. school; mealtime vs. circle time) and with different interlocutors (e.g., siblings, peers, parents) (Dunn and Shatz, 1989; Dunn, 1996; Slomkowski and Dunn, 1996; Pan and Snow, 1999). Navigating these different contexts requires very flexible linguistic skills, and although preschoolers are not yet fully fluent, the preschool years bring great advances in the ability to use language appropriately in different situations.

## 2.30.5 What is Learned in Later Childhood

### 2.30.5.1 Learning the Nuances

A cursory survey of the child language literature indicates that children show basic fluency by 4 years of age and mastery of basic morphological and syntactic structures by about 5 years.

What remains to develop is the ability to apply basic linguistic knowledge in contexts that are more challenging or complex, or that require integration of linguistic and paralinguistic (and nonlinguistic) information within and between utterances. For example, Campbell and Bowe (1983) told children stories with a low-frequency homonym (e.g., during a car trip a "hare ran across the road"). Children were shown to interpret 'hare' in its dominant meaning (i.e., 'hair'), though this interpretation was nonsensical. Although children have difficulty learning homonyms (Doherty, 2004), and answering ambiguous questions (Waterman et al., 2000), this particular error involves integrating information across utterances in order to interpret (i.e., represent meaning of) a statement. Similarly, 6-year-olds have trouble flexibly attending to paralanguage and semantic content to interpret mixed messages (e.g., "My mommy gave me a treat" said in a sad voice); they tend to rigidly attend only on the most salient kind of information (Morton et al., 2003). This might explain older children's difficulty understanding jokes, irony, and sarcasm. In general, as children get older they can make more precise and context-appropriate inferences about a speaker's meaning, while maintaining syntactic, semantic, and pragmatic coherence over longer passages of conversation or narrative. This expansion in the 'scope' of linguistic performance is seen in semantic, syntactic, and discourse processing.

#### 2.30.5.1.1 Learning the nuances of relational semantics

Children sometimes have difficulty inferring the extensions of semantic relations, especially when novel words are involved. Class inclusion relations (inclusion, overlap, and exclusion) are among the simplest between categories (though not the only ones; e.g., Lakoff, 1987). Thus, the assertion "some fish are eaten" requires representing some overlap between two classes (fish and food).

Recall that by 3 years children can use familiar words in semantically appropriate ways (Deák and Maratsos, 1998). By 4–5 years they can infer the relation of a novel word to familiar ones based on class inclusion statements. For example if told "A *pug* is a dog" (where *pug* is novel), kindergartners usually infer that a pug must be an animal, but do not infer that a pug is a dog if told "A pug is an animal" (Smith, 1979). Still, the use of semantic information improves with age. Deák and Wagner (2003) attempted to teach children several novel words and the relations between them using class-inclusion statements. Four- and 5-year-olds learned few relations, whereas 6- and 7-year-olds learned most. It is unknown why older children are better at using direct input to learn semantic relations. Perhaps they sometimes analogize from familiar semantic relations (Johnson et al., 1997).

#### 2.30.5.1.2 Learning complex online syntactic judgments

Another synthetic linguistic skill is interpreting syntactic relations in the 'real time' of conversation. Adults quickly and reliably determine when a sentence is irreparably ungrammatical, as from an agreement error. However, adults can also withhold judgments in the face of an ambiguous sentence until all 'legal' interpretations of syntactic structure have been checked. For example in an auxiliary omission error such as "Mrs. Brown working at the library called home to say she would be late," adults can withhold judgment until the end of the sentence (Blackwell et al., 1996). Children, by contrast, prematurely try to resolve syntactic ambiguities before parsing is complete.

For instance, Trueswell et al. (1999; Hurewitz et al., 2000) demonstrated that 5-year-olds prematurely resolve a noun-modifier clause (e.g., "Put the frog on the napkin in the bowl") as destination-marking prepositional phrase. That is, they interpret "on the napkin" as a destination marker, placing an isolated toy frog onto an empty napkin instead of putting a frog already on a napkin into a bowl. The error unfolds as children listen to the sentence, as shown by eye-movement analysis: whereas adults shift gaze to the frog on the napkin, 5-year-olds look at the incorrect (second) frog early and do not show awareness of the ambiguity of the modifier. Interestingly, 5-year-olds can in other contexts correctly produce the same syntactic structure. Thus even when children can produce complex syntactic structures, they may make on-line parsing errors.

Children's syntactic judgments also become faster from 6 to 10 years. Children in this age range are in general slower than adults at detecting violations of agreement or word order, and are relatively slower to notice violations early in a sentence rather than late in the sentence (Kail, 2004). Moreover, semantic incongruity within a sentence seems to distract 6-year-olds and keep them from noticing syntax errors (Windsor, 1999). Such findings suggest limitations of working memory or processing efficiency. Grammaticality judgments require holding several sentence constituents in memory, and increased processing speed and efficiency from 2 to 10 years (Kail, 1991), as well as increased verbal working memory capacity (Gathercole et al., 1992), should make syntactic processing faster and more reliable.

#### 2.30.5.1.3 Learning the nuances: reference, pragmatics, and implicature

Syntactic judgments and constructions fundamentally involve pragmatic factors (Bates and MacWhinney, 1982). As children gain fluency, and adults expect them to maintain good discourse cohesion, they must master a wide variety of devices for maintaining good discourse cohesion: topic–introducing-and-shifting (e.g., "There was this guy. He..."), topic-continuing (e.g., "yeah, and..."), perspective-shifting (e.g., "No, *he* didn't do it, *she* did!"), etc. As these examples show, pronouns and generic descriptions are important elements of discourse (Karmiloff-Smith, 1979). Adults, for example, find it jarring to continue to use unique individuation within a narrative:

> Chris and Heidi went to a new restaurant. The waitress asked Chris and Heidi if Chris and Heidi wanted drinks. "No," said Heidi. Heidi had already had some wine.

Preschoolers can use pronouns for coherent reference; for example they use simple cues (e.g., gender) to pick out a pronoun referent (Blakemore, 1990). Five-year-olds who lag behind in this ability show other narrative comprehension deficits (Cain and Oakhill, 1999; Yuill and Oakhill, 1991). By 7 years, however, children select and substitute pronouns in more pragmatically appropriate ways (Lloyd et al., 1995; Hickman and Hendricks, 1999). Specifically, the ability to use an interlocutor's knowledge to select unambiguous referential terms develops from 4 to 7 years (Ackerman, 1993), during the same period when they improve at drawing inferences about a speaker's meaning based on nonliteral semantic and discourse implications (e.g., Özçalıskan, 2004).

### 2.30.5.2 From Fluency to Flexibility and Meta-Language

#### *2.30.5.2.1 Cognitive flexibility in child language*

Each of the linguistic achievements of late childhood involves greater precision of interpretation or production. This precision requires representing different perspectives (Clark, 1997), which in turn requires representational flexibility (Deák, 2003). Flexibility involves processes including shifting attention, generating/selecting new representations, suppressing prior cues and associations, etc. Deák (2000b; 2003) found that children's flexibility in using cues to infer novel word meanings develops from 3 to 6 years, and individual differences in flexibility predict vocabulary, but are unrelated to children's ability to inhibit lexical associations. One interpretation is that word-learning flexibility is independent of some related cognitive control processes, but nevertheless predicts word-learning efficacy. A significant question is whether the same kind of cue-using flexibility is used by children to make complex syntactic and discourse interpretation. There is as yet no evidence addressing this question.

Cognitive flexibility encompasses children's growing ability to formulate and select appropriate but nonobvious representations of a referent or sentence in light of contextual information. For instance, interpreting /har/ as a synonym for rabbit, not hair (Campbell and Bowe, 1983), requires flexibility and selectivity in retrieving alternate word meanings. Such sorts of cognitive control are prominent in mature language abilities.

Some claims about the development of cognitive flexibility have focused on limitations on cognitive resources such as working memory and inhibitory processes (Diamond, 1998). Evidence for these claims is mixed at best (Deák and Narasimham, 2003; Zelazo et al., 2003), but there is so little research on effects of working memory and inhibition on flexible representations during language processing that the matter is unresolved.

Another idea is that cognitive flexibility, including flexible language processing, rests on children's developing ability to coordinate multiple response-contingencies in their response selection (Zelazo et al., 2003). For example, Zelazo et al. (2003) claim 3-year-olds cannot use a two-level hierarchy of verbal rules to guide classification responses. Three-year-olds readily sort cards by either of two rules (color or shape), for example, but when asked to switch from one to the other they continue to follow the first rule (Zelazo et al., 1996). Is the problem their inability to handle the complexity of a hierarchy of rules? It seems 3-year-olds use quite complex linguistic contingencies to formulate or interpret syntactic utterances, at least in ideal circumstances (e.g., Bates and MacWhinney, 1982; Slobin, 1982), so it is difficult to assimilate natural language performance into Zelazo et al.'s (2003) theory. However, there is some evidence that children who do not flexibly respond to changing rules can benefit from semantic and pragmatic support (Munakata and Yerys, 2001; Kirkham et al., 2003). Also, studies of feedback suggest that children's errors are based on misunderstanding the rules or failing to notice rule-switch cues (Bohlmann and Fenson, 2005), consistent with the argument that cue comprehension is a critical factor in children's linguistic flexibility (Deák, 2003). Although it remains unclear how late-developing language skills intersect with the development of cognitive control, the two are not strongly correlated in individual 4- and 7-year-olds (Brophy et al., 2002), suggesting some dissociation.

#### *2.30.5.2.2 Becoming an expert language user*

As children's language skills become consolidated, they become faster and more accurate, especially when processing or producing more complex and novel utterances. This is hardly surprising but it raises key issues. One is that there are no neurobiological accounts of later language development. This is surprising given recent findings that fairly brief language training interventions can measurably change children's neural activity during language processing. This indicates prolonged neural plasticity (Shaywitz et al., 2004).

Another issue is that the large literature on expertise acquisition (Feltovich et al., 2006) is disconnected from the literature on later language development – which might be considered a nearly universal type of human expertise. The result of this disconnect is an odd conceptual separation of similar phenomena. For example, children acquire expertise in phonology such that lexical representations are organized in phonological similarity neighborhoods (Luce and Pisoni, 1998), which have characteristic perceptual expertise effects (Vitevitch, 1997). Five- to 7-year-olds have fewer similarity neighborhoods than adults (Charles-Luce and Luce, 1990), but these become refined with phonological and vocabulary development. Another near-universal form of human expertise, face processing (Gauthier et al., 1999), is acquired in ways that reveal plasticity and input-driven effects. It is likely that in the next decade language expertise, like face processing and other examples of childhood expertise, will no longer be viewed in outmoded nativist terms, but as a complex, emergent product of input-expectant learning.

#### 2.30.5.2.3 Knowledge about language

Older children develop metalinguistics, or the ability to reflect on language (Gombert, 1992). Metalinguistic awareness focuses on dissociation of representations, as between a word as an action and as a symbol of whatever it represents. For example children might have trouble judging which is a longer *word:* 'mosquito' or 'cow,' because they conflate the words with their referents. Metalinguistic development might facilitate discourse facility (e.g., Morton et al., 2003): to the extent that specific lexical and syntactic acts underspecify a speaker's meaning, the ability to reflect on speech acts *per se* can help children understand nonliteral language (e.g., irony, sarcasm, or figurative language; Levorato and Cacciari, 2002).

Young children's metalinguistic knowledge has been tested in synonym and homonym usage. Doherty et al. (2004) found preschoolers' ability to identify homonym word pairs (baseball bat vs. flying bat) improved from 3 to 4 years of age and predicted understanding of false beliefs (i.e., inferring that another person can have an incorrect belief) even when vocabulary development was controlled. This suggests that metalinguistic knowledge develops in conjunction with other meta-representational skills.

How does metalinguistic knowledge develop? Older preschoolers show a tenuous association of printed word to referential meaning (Bialystok, 1997). However, this seems to improve with bilingual experience, possibly because bilingual children have more experience dealing with the abstract nature of linguistic representations as they switch codes to talk with different people (Bialystok et al., 2000). However, this argument is tentative, as there is so little research on the development of metalinguistic knowledge.

## 2.30.6 Conclusions

Three critical positions have been alluded to above, and these are central to the ongoing study of child language learning.

First, as advances in neuroscience fundamentally change our understanding of human cognition, they challenge persistent myths and assumptions about language. Basic findings about the developing bases of language in the brain, including the plasticity of language development (Bates et al., 2003), render ideas like Chomsky's 'language acquisition device' quaint. The growing sophistication of computational simulations of language learning support neurally plausible accounts of language development. However, because methods for measuring neural function and change in infants and children are so limited, much remains to be discovered.

Second, despite extensive use of terms like 'syntax,' 'semantic,' 'morphology,' and 'discourse,' these are conveniences based on historical convention in linguistics. Though there do seem to be some aspects of nearly pure syntactic knowledge, for example (Maratsos, 1998), more typical are complex interrelations among aspects of linguistic knowledge (e.g., Hay and Baayen, 2005). For example, there are no *a priori* neural dissociations between syntax and semantics (Bates et al., 2002). The interrelatedness of linguistic knowledge can be shown in children as well as adults. An intriguing question is how neural and psychological specialization of various aspects of language emerge during development.

Finally, research on different populations, including infants and children with various developmental disorders, and adults with neurological and sensory deficits, and a wide range of languages, will be necessary to understand typical language development. Studies of communicative learning in nonhuman species, and of nonlinguistic learning in humans (e.g., Childers and Tomasello, 2003) are also necessary. Despite the challenges of synthesizing such a vast range of research, the history of child language research clearly shows that a myopic focus on competent, healthy, educated English speakers leads to mistaken assumptions about the nature of language and language learning.

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## References

Ackerman BP (1993) Children's understanding of the relation between referential knowledge and referential behavior. *J. Exp. Child Psychol.* 56: 385–411.

Akhtar N, Carpenter M, and Tomasello M (1996) The role of discourse novelty in early word learning. *Child Dev.* 67: 635–645.

Akhtar N and Tomasello M (1997) Young children's productivity with word order and verb morphology. *Dev. Psychol.* 33: 952–965.

Anglin JM (1993) *Vocabulary Development: A Morphological Analysis.* Monographs of the Society for Research in Child Development, 58(10), serial no. 238. Oxford: Blackwell.

Au TK and Glusman M (1990) The principle of mutual exclusivity in word learning: To honor or not to honor? *Child Dev.* 61: 1474–1490.

Baker SA, Golinkoff RM, and Petitto LA (2006) New insights into old puzzles from infants' categorical discrimination of soundless phonetic units. *Lang. Learn. Dev.* 2: 147–162.

Baldwin DA (1995) Understanding the link between joint attention and language. In: Moore C and Dunham P (eds.) *Joint Attention: Its Origins and Role in Development*, pp. 131–158. Hillsdale, NJ: Lawrence Erlbaum Associates.

Baldwin DA and Moses LJ (2001) Links between social understanding and early word learning: Challenges to current accounts. *Soc. Dev.* 10: 309–329.

Barton DP (1980) Phonemic perception in children. In: Yeni-Komshian G, Kavanagh JF, and Ferguson CA (eds.) *Child Phonology: Vol. 2. Perception*, pp. 97–114. New York: Academic Press.

Bates E and Goodman JC (1999) On the emergence of grammar from the lexicon. In: MacWhinney B (ed.) *The Emergence of Language*, pp. 29–79. Mahwah, NJ: Lawrence Erlbaum Associates.

Bates E and MacWhinney B (1982) Functionalist approaches to grammar. In: Wanner E and Gleitman L (eds.) *Language Acquisition: The State of the Art*, pp. 173–218. Cambridge, MA: MIT Press.

Bates E, Thal D, Finlay BL, and Clancy B (2003) Early language development and its neural correlates. In: Segalowitz SJ and Rapin I (eds.) *Handbook of Neuropsychology, Vol. 8, Part II, Child Neuropsychology,* 2nd edn., pp. 525–592. Amsterdam: Elsevier Science.

Bialystok E (1997) Effects of bilingualism and biliteracy on children's emerging concepts of print. *Dev. Psychol.* 33: 429–440.

Bialystok E, Shenfield T, and Codd J (2000) Languages, scripts, and the environment: Factors in developing concepts of print. *Dev. Psychol.* 36: 66–76.

Birdsong D (1992) Ultimate attainment in second language acquisition. *Language* 68: 706–755.

Blackwell A, Bates E, and Fisher D, (1996) The time course of grammaticality judgment: Language and cognitive processes. *Lang. Cogn. Process.* 11(4): 337–406.

Blakemore D (1990) Constraints on interpretations. In: *Proceedings of the 16th Annual Meeting of the Berkeley Linguistic Society.* Parassession on the Legacy of Grice, pp. 363–370.

Braine MDS (1976) Children's first word combinations. *Monographs of the Society for Research in Child Development*, 41(1), no. 164. Chicago: University of Chicago Press.

Bloom L, Lightbown P, and Hood L (1975) *Structure and Variation in Child Language.* Monographs of the Society for Research in Child Development, 40(2), no. 160. Chicago: University Of Chicago Press.

Bohlmann NL and Fenson L (2005) The effects of feedback on perseverative errors in preschool aged children. *J. Cogn. Dev.* 6: 119–131.

Bornstein MH, Haynes OM, and Painter KM (1998) Sources of child vocabulary competence: A multivariate model. *J. Child Lang.* 25: 367–393.

Braine MDS (1992) What sort of innate structure is needed to ''bootstrap'' into syntax? *Cognition* 45: 77–100.

Brent MR and Siskind JM (2001) The role of exposure to isolated words in early vocabulary development. *Cognition* 81: B33–B44.

Brooks R and Meltzoff AN (2002) The importance of eyes: How infants interpret adult looking behavior. *Dev. Psychol.* 38: 958–966.

Brophy M, Taylor E, and Hughes C (2002) To go or not to go: Inhibitory control in 'hard to manage'children. *Infant Child Dev.* 11: 125–140.

Brown P (1998) Conversational structure and language acquisition: The role of repetition in Tzeltal. *J. Linguist. Anthropol.* 8: 197–221.

Butterworth GE and Jarrett NLM (1991) What minds have in common is space: Spatial mechanisms serving joint visual attention in infancy. *Br. J. Dev. Psychol.* 9: 55–72.

Cain K and Oakhill JV (1999) Inference making ability and its relation to comprehension failure in young children. *Reading Writing Interdiscip. J.* 11: 489–503, 1999.

Callanan MA (1990) Parents' descriptions of objects: Potential data for children's inferences about category principles. *Cogn. Dev.* 5: 101–122.

Campbell RN and Bowe TB (1983) Text and context in early language comprehension. In: Donaldson M, Grieve R, and Pratt C (eds.) *Early Childhood Development and Education*, pp. 115–126. Oxford: Blackwell.

Caselli MC, Casadio P, and Bates E (1999) A comparison of the transition from first words to grammar in English and Italian. *J. Child Lang.* 26: 69–111.

Cazden CB (1968) The acquisition of noun and verb inflections. *Child Dev.* 39: 433–448.

Chapman KL, Leonard LB, and Mervis CB (1986) The effect of feedback on young children's inappropriate word usage. *J. Child Lang.* 13: 101–117.

Charles-Luce J and Luce PA (1990) Similarity neighbourhoods of words in young children's lexicons. *J. Child Lang.* 17: 205–215.

Childers JB and Tomasello M (2002) 2-year-olds learn novel nouns, verbs, and conventional actions from massed or distributed exposures. *Dev. Psychol.* 38: 967–978.
Childers JB and Tomasello M (2003) Children extend both words and non-verbal actions to novel exemplars. *Dev. Sci.* 6: 185–190.
Choi S, McDonough L, Bowerman M, and Mandler J (1999) Early sensitivity to language-specific spatial categories in English and Korean. *Cogn. Dev.* 14: 241–268.
Clark EV (1973) What's in a word? On the child's acquisition of semantics in his first language. In: Moore T (ed.), *Cognitive Development and the Acquisition of Language*, pp. 65–110. New York: Academic Press.
Clark EV (1997) Contextual perspective and lexical choice in acquisition. *Cognition,* 64: 1–37.
Clark EV and Svaib TA (1997) Speaker perspective and reference in young children. *First Lang.* 17: 57–74.
Cooper RP and Aslin RN (1990) Preference for infant-directed speech in the first month after birth. *Child Dev.* 61: 1584–1595.
Deacon T (1997) *The Symbolic Species*. Cambridge, MA: Harvard.
Deák GO (2000a) Chasing the fox of word learning: Why ''constraints'' fail to capture it. *Dev. Rev.* 20: 29–80.
Deák GO (2000b) The growth of flexible problem solving: Preschool children use changing verbal cues to infer multiple word meanings. *J. Cogn. Dev.* 1: 157–192.
Deák GO (2003) The development of cognitive flexibility and language abilities. In: Kail R (ed.) *Advances in Child Development and Behavior,* vol. 31, pp. 271–327. San Diego: Academic Press.
Deák GO, Flom R, and Pick AD (2000) Perceptual and motivational factor affecting joint visual attention in 12- and 18-month-olds. *Dev. Psychol.* 36: 511–523.
Deák G, Krasno A, Jasso H, and Triesch J (2006). *Watch the Hands: Infants Learn Gaze-Following from Parents' Pointing and Manual Actions.* XVth Biennial International Conference on Infant Studies, Westin Miyako, Kyoto, Japan, Jun 19, 2006.
Deák GO and Maratsos M (1998) On having complex representations of things: Preschoolers use multiple words for objects and people. *Dev. Psychol.* 34: 224–240.
Deák GO and Narasimham G (2003) Is perseveration caused by inhibition failure? Evidence from preschool children's inferences about word meanings. *J. Exp. Child Psychol.* 86: 194–222.
Deák GO and Triesch J (2006) Origins of shared attention in human infants. In: Fujita K and Itakura S (eds.) *Diversity of Cognition*, pp. 331–366. Kyoto, Japan: University of Kyoto Press.
Deák GO and Wagner JH (2003) ''Slow mapping'' in children's learning of semantic relations. *Proceedings of the 25th Annual Conference of the Cognitive Science Society*, pp. 318–323. Hillsdale, NJ: Lawrence Erlbaum Associates.
Deák GO, Yen L, and Pettit J (2001) By any other name: When will preschoolers produce multiple labels for a referent? *J. Child Lang.* 28: 787–804.
DeCasper AJ and Fifer WP (1980) Of human bonding: Newborns prefer their mothers' voices. *Science,* 208: 1174–1176.
Devescovi A, Caselli MC, Marchione D, Pasqualetti P, Reilly J, and Bates E (2005) A crosslinguistic study of the relationship between grammar and lexical development. *J. Child Lang.* 32: 759–786.
Diamond A (1998) Evidence of the importance of dopamine for prefrontal cortex functions early in life. In: Roberts A, Robbins T, and Weiskrantz L (eds.) *The Prefrontal Cortex*, pp. 144–164. Oxford: University Press.
Diesendruck G, Markson L, Akjtar N, and Reudor A (2004) Two-year-olds' sensitivity to speakers' intent: An alternative account of Samuelson and Smith. *Dev. Sci.* 7: 33–41.
Doherty MJ (2004) Children's difficulty in learning homonyms. *J. Child Lang.* 31: 203–214.
Dunn J (1996) Family conversations and the development of social understanding. In: Bernstein B and Brannen J (eds.) *Children: Research and Policy*, pp. 81–95. London: Taylor and Francis.
Dunn J and Shatz M (1989) Becoming a conversationalist despite (or because of) having a sibling. *Child Dev.* 60: 399–410.
Eimas PD (1974) Auditory and linguistic processing of cues for place of articulation by infants. *Percept. Psychophysiol.* 16: 513–521.
Eimas PD, Siqueland ER, Jusczyk PW, and Vigorito J (1971) Speech perception in infants. *Science* 171: 303–306.
Elman JL (1993) Learning and development in neural networks: The importance of starting small. *Cognition* 48: 71–99.
Elman JL, Bates EA, Johnson MH, Karmiloff-Smith A, Parisi D, and Plunkett K (1996) *Rethinking Innateness*. Cambridge, MA: MIT Press.
Enard W, Przeworski M, Fisher SE, et al. (2002) Molecular evolution of FOXP2, a gene involved in speech and language. *Nature* 418: 869–872.
Fantz RL (1963) Pattern vision in newborn infants. *Science* 140: 296–297.
Feltovich PJ, Prietula MJ, and Ericsson KA (2006) Studies of expertise from psychological perspectives. In: Ericsson KA, Charness N, Feltovich PJ, and Hoffman RR (eds.) *The Cambridge Handbook of Expertise and Expert Performance*, pp. 41–68. Cambridge: Cambridge University Press.
Fenson L, Dale PS, Reznick JS, Bates E, Thal DJ, and Pethick SJ (1994) *Variability in Early Communicative Development. Monographs of the Society for Research in Child Development*, 59(5), serial no. 242. Chicago: University of Chicago Press.
Fernald A and Mazzie C (1991) Prosody and focus in speech to infants and adults, *Dev. Psychol.* 27: 209–221.
Fernald A, Taeschner T, Dunn J, Papousek M, de Boysson-Bardies B, and Fukui I (1989) A cross-language study of prosodic modifications in mothers' and fathers' speech to preverbal infants. *J. Child Lang.* 16: 477–501.
Fisher C, Church BA, and Chambers KE (2004) Learning to identify spoken words. In: Hall D and Waxman S (eds.) *Weaving a Lexicon*, pp. 3–40. Cambridge, MA: MIT Press.
Flege JE (1999) Age of learning and second language speech. In: Birdsong D (ed.) *Second Language Acquisition and the Critical Period Hypothesis*, pp. 101–131. Mahwah, NJ: Lawrence Erlbaum Associates.
Flom R and Pick AD (2003) Verbal encouragement and joint attention in 18-month-old infants. *Infant Behav. Dev.* 26: 121–134.
Gasser M and Smith LB (1998) Learning nouns and adjectives. A connectionist account. *Language and Cognitive Processes,* 13: 269–306.
Gathercole SE, Willis C, Emslie H, and Baddeley AD (1992) Phonological memory and vocabulary development during the early school years: A longitudinal study. *Dev. Psychol.* 28: 887–898.
Gauthier MJ, Tarr AW, Anderson AW. Skudlarski P, and Gore JC (1999) Activation of the middle fusiform face area increases with expertise in recognizing novel objects. *Nat. Neurosci.* 2: 568–573.
Gogate LJ and Bahrick LE (1998) Intersensory redundancy facilitates learning of arbitrary relations between vowel sounds and objects in 7-month-old infants. *J. Exp. Child Psychol.* 69: 133–49.

Gogate LJ and Bahrick LE (2001) Intersensory redundancy and 7-month-old infants' memory for syllable-object relations. *Infancy* 2: 219–31.

Golinkoff RM and Alioto A (1995) Infant-directed speech facilitates lexical learning in adults hearing Chinese: Implications for language acquisition. *J. Child Lang.* 22: 703–726.

Gombert JE (1992) *Metalinguistic Development*. Chicago: University of Chicago Press.

Gómez RL and Gerken L (2000) Infant artificial language learning and language acquisition. *Trends Cogn. Sci.* 4: 178–186.

Gopnik A and Meltzoff AN (1992) Categorization and naming: Basic-level sorting in 18-month-olds and its relation to language. *Child Dev.* 63: 1091–1103.

Gopnik M (1997) Language deficits and genetic factors. *Trends Cogn. Sci.* 1: 5–9.

Gordon P (1985) Level-ordering in lexical development. *Cognition* 21: 73–93.

Grieser DL and Kuhl PK (1998) Maternal speech to infants in a tonal language: Support for universal prosodic features in motherese. *Dev. Psychol.* 24: 14–20.

Hadley RF, Rotaru-Varga A, Arnold D, and Cardei V (1998) Syntactic systematicity arising from semantic predictions in a Hebbian-competitive network. In: *Proceedings of the 20th Annual Conference of the Cognitive Science Society*, pp. 460–465. Hillsdale, NJ: Lawrence Erlbaum Associates.

Hakuta K, Bialystok E, and Wiley E (2003) Critical evidence: A test of the critical-period hypothesis for second-language acquisition. *Psychol. Sci.* 14: 31–38.

Hart B and Risley T (1995) *Meaningful Differences in the Everyday Experiences of Young Children*. Baltimore, MD: Paul H. Brookes.

Hauser MD, Newport EL, and Aslin RN (2001) Segmentation of the speech stream in a non-human primate: Statistical learning in cotton-top tamarins. *Cognition* 78: B53–B64.

Hay JB and Baayen RH (2005) Shifting paradigms: Gradient structure in morphology. *Trends Cogn. Sci.* 9: 342–348.

Heath SB (1983) *Ways with Words*. Cambridge: Cambridge University Press.

Hickmann M and Hendriks H (1999) Cohesion and anaphora in children's narratives: A comparison of English, French, German, and Mandarin Chinese. *J. Child Lang.* 26: 419–452.

Hirsh-Pasek K and Golinkoff R (1996) *The Origins of Grammar*. Cambridge, MA: MIT Press.

Hirsh-Pasek K, Kemler Nelson DG, Jusczyk PW, et al. (1987) Clauses are perceptual units for young infants. *Cognition* 26: 269–286.

Hurewitz F, Brown-Schmidt S, Thorpe K, Gleitman LR, and Trueswell JC (2000) One frog, two frog, red frog, blue frog: Factors affecting children's syntactic choices in production and comprehension. *J. Psycholinguist. Res.* 29(6): 597–626.

Huttenlocher J and Smiley P (1987) Early word meanings: The case of object names. *Cognit. Psychol.,* 63.

Johnson JS and Newport EL (1989) Critical period effects in second language learning: The influence of maturational state on the acquisition of English as a second language. *Cognit. Psychol.* 21: 60–99.

Johnson K, Scott P, and Mervis CB (1997) Development of children's understanding of basic-subordinate inclusion relations. *Dev. Psychol.* 33: 745–763.

Jusczyk PW (1997) *The Discovery of Spoken Language*. Cambridge, MA: MIT Press.

Jusczyk PW and Aslin RN (1995) Infants' detection of the sound patterns of words in fluent speech. *Cognit. Psychol.* 29: 1–23.

Jusczyk PW, Cutler A, and Redanz N (1993) Preference for the predominant stress patterns of English words. *Child Dev.* 64: 675–687.

Jusczyk PW and Hohne EA (1997) Infants' memory for spoken words. *Science* 277: 1984–1986.

Kail M (2004) On-line grammaticality judgments in French children and adults: A crosslinguistic perspective. *J. Child Lang.* 31: 713–737.

Kail R (1991) Developmental change in speed of processing during childhood and adolescence. *Psychol. Bull.* 109: 490–501.

Karmiloff-Smith A (1979) *A Functional Approach to Child Language*. Cambridge (UK): Cambridge University Press.

Karmiloff-Smith A (1998) Development itself is the key to understanding developmental disorders. *Trends Cogn. Sci.* 2: 389–398.

Kirkham N, Creuss L, and Diamond A (2003) Helping children apply their knowledge to their behavior on a dimension-switching task. *Dev. Sci.* 6: 449–476.

Kirkham NZ, Slemmer JA, and Johnson SP (2002) Visual statistical learning in infancy: Evidence for a domain general learning mechanism. *Cognition* 83: B35–B42.

Krumhansl CL and Jusczyk PW (1990) Infants' perception of phrase structure in music. *Psychol. Sci.* 1: 70–73.

Lai CS, Fisher SE, Hurst JA, Vargha-Khadem F, and Monaco AP (2001) A forkhead-domain gene is mutated in a severe speech and language disorder. *Nature* 413: 519–523.

Lakoff G (1987) *Women, Fire, and Dangerous Things*. Chicago: University Press.

Lenneberg EH (1967) *Biological Foundations of Language*. New York: Wiley.

Levorato MC and Cacciari C (2002) The creation of new figurative expressions: Psycholinguistic evidence in Italian children, adolescents and adults. *J. Child Lang.* 29: 127–150.

Lewis JD and Elman JL (2001) A connectionist investigation of linguistic arguments from poverty of the stimulus: Learning the unlearnable. In: *Proceedings of the 23rd Annual Conference of the Cognitive Science Society*, pp. 552–557. Hillsdale, NJ: Lawrence Erlbaum Associates.

Lieven EVM (1994) Crosslinguistic and crosscultural aspects of language addressed to children. In: Gallaway C and Richards BJ (eds.) *Input and Interaction in Language Acquisition*, pp. 56–73. Cambridge: Cambridge University Press.

Liittschwager JC and Markman EM (1994) 16- and 24-month-olds' use of mutual exclusivity as a default assumption in second-label learning. *Dev. Psychol.* 6: 955–968.

Lloyd P, Camaioni L, and Ercolani P (1995) Assessing referential communication skills in the primary school years: A comparative study. *Br. J. Dev. Psychol.* 13: 13–29.

Loveland KA and Landry SH (1986) Joint attention and language in autism and developmental language delay. *J. Autism Dev. Disord.* 16: 335–349.

Luce PA and Pisoni DB (1998) Recognizing spoken words: The neighborhood activation model. *Ear Hear.* 19: 1–36.

MacWhinney B (1978) *Processing a First Language: The Acquisition of Morphophonology.* Monographs of the Society for Research on Child Development, 43, no. 174. Oxford: Blackwell.

Mandel DR, Jusczyk PW, and Pisoni DB (1995) Infants' recognition of the sound patterns of their own names. *Psychol. Sci.* 6: 314–317.

Mandel DR, Kemler Nelson DG, and Jusczyk PW (1996) Infants remember the order of words in a spoken sentence. *Cogn. Dev.* 11: 181–196.

Maratsos M (1998) The acquisition of grammar. In: Kuhn D and Siegler R (Volume eds.), Damon W (Series ed.) *Handbook of Child Psychology, 5th edn., Vol. 2: Cognition, Perception, and Language*, pp. 421–466. New York: Wiley.

Maratsos M and Chalkley MA (1980) The internal language of children's syntax: The ontogenesis and representation of

syntactic categories. In: Nelson K (ed.) *Children's Language,* Vol. II, pp. 127–214. New York: Gardner Press.
Marcus GF, Vijayan S, Bandi Rao S, and Vishton PM (1999) Rule learning by seven-month-old infants. *Science* 283: 77–80.
Marcus G, Pinker S, Ullman M, Hollander M, Rosen TJ, and Xu F (1992) *Overregularization in Language Acquisition.* Monographs of the Society for Research on Child Development. 57(4), no. 228. Oxford: Blackwell.
Markman EM (1992) Constraints on word learning: Speculations about their nature, origins, and domain specificity. In: Gunnar M and Maratsos M (eds.) *The Minnesota Symposium on Child Psychology,* vol. 25, pp. 59–101. Hillsdale, NJ: Lawrence Erlbaum Associates.
Mayberry RI and Lock E (2003) Age constraints on first versus second language acquisition: Evidence for linguistic plasticity and epigenesis. *Brain Lang.* 87: 369–384.
McClelland J, Fiez J, and McCandliss B (2002) Teaching the /r/-/l/ discrimination to Japanese adults: Behavioral and neural aspects. *Physiol. Behav.* 77: 657–662.
Mehler J and Christophe A (1994) Language in the infant's mind. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 346: 13–20.
Mervis CB, Golinkoff RM, and Bertrand J (1994) Two-year-olds readily learn multiple labels for the same biasic-level category. *Child Dev.* 65: 1163–1177.
Morgan JL, Allopena P, and Shi R (1996) Perceptual bases of rudimentary grammatical categories : Toward a broader conceptualization of bootstrapping. In: Morgan J and Demuth K (eds.) *Signal to Syntax*, pp. 263–286. Mahwah, NJ: Lawrence Erlbaum Associates.
Morris W, Cottrell G, and Elman J (2000) A connectionist simulation of the empirical acquisition of grammatical relations. In: Wermter S and Sun R (eds.) *Hybrid Neural Systems*, pp. 175–193. Springer Verlag, Heidelberg.
Morton JB, Trehub SE, and Zelazo PD (2003) Sources of inflexibility in 6-year-olds' understanding of emotion in speech. *Child Dev.* 74: 1857–1868.
Munakata Y and Yerys BE (2001) All together now: When dissociations between knowledge and action disappear. *Psychol. Sci.* 12: 335–337.
Mundy P, Sigman M, and Kasari C (1990) A longitudinal study of joint attention and language development in autistic children. *J. Autism Dev. Disord.* 20: 115–128.
Naigles L (1990) Children use syntax to learn verb meanings. *J. Child Lang.* 17: 357–374.
Naigles LR (2002) Form is easy, meaning is hard: Resolving a paradox in early child language. *Cognition* 86: 157–199.
Naigles L, Fowler A, and Helm A (1992) Developmental shifts in the construction of verb meanings. *Cogn. Dev.* 7: 403–428.
Namy LL and Waxman SR (1998) Words and gestures: Infants' interpretations of different forms of symbolic reference. *Child Dev.* 69: 295–308.
Nazzi T, Bertoncini J, and Mehler J (1998) Language discrimination by newborns: Towards an understanding of the role of rhythm. *J. Exp. Psychol. Hum. Percept. Perform.* 24: 756–766.
Nelson K (1973) *Structure and Strategy in Learning to Talk.* Monographs of the Society for Research on Child Development. 38, no. 149. Oxford: Blackwell.
Nelson K (1979) Explorations in the development of a functional semantic system. In: Collins WA (ed.) *The Minnesota Symposium on Child Psychology,* Vol. 12, pp. 47–81. Hillsdale, NJ: Lawrence Erlbaum Associates.
Ninio A and Snow C (1996) *Pragmatic Development*. Boulder, CO: Westview Press.
Ohl FW and Scheich H (2005) Learning-induced plasticity in animal and human auditory cortex. *Curr. Opin. Neurobiol.* 15: 470–477.
O'Neill DK (1996) Two-year-old children's sensitivity to a parent's knowledge state when making requests. *Child Dev.* 67: 659–677.
Öz S (2004) Time can't fly, but a bird can: Learning how to think and talk about time as spatial motion in English and Turkish. *Eur. J. English Lang.* 8: 309–336.
Pan BA, Imbents-Bailey A, Winner K, and Snow C (1996) Communicative intents expressed by parents in interaction with young children. *Merrill-Palmer Q.* 42: 248–266.
Pan BA and Snow C (1999) The development of conversational and discourse skills. In: Barrett M (ed.) *The Development of Language*, pp. 229–249. London: Taylor and Francis.
Pegg JE, Werker JF, and McLeod PJ (1992) Preference for infant-directed over adult-directed speech: Evidence from 7-week-old infants. *Infant Behav. Dev.* 15: 415–440.
Petitto LA and Marentette PF (1991) Babbling in the manual mode: Evidence for the ontogent of language. *Science* 251: 1493–1496.
Pilon R (1981) Segmentation of speech in a foreign language. *J. Psycholinguist. Res.* 10: 113–121.
Pinker S (1984) *Language, Learnability, and Language Development*. Cambridge, MA: MIT Press.
Plunkett K, Sinha C, Mϕller MF, and Strandsby O (1992) Symbol grounding or the emergence of symbols? Vocabulary growth in children and a connectionist net. *Connection Sci.* 4: 293–331.
Pullum GK and Scholz BC (2002) Empirical assessment of stimulus poverty arguments. *Linguist. Rev.* 19: 9–50.
Rescorla L (1980) Overextensions in early language development. *J. Child Lang.* 7: 312–335.
Saffran JR, Aslin RN, and Newport EL (1996) Statistical learning by 8-month-old infants. *Science* 274: 1926–1928.
Saffran JR, Johnson EK, Aslin RN, and Newport EL (1999) Statistical learning of tone sequences by human infants and adults. *Cognition* 70: 27–52.
Sandler W, Meir I, Padden C, and Aronoff M (2005) The emergence of grammar: Systematic structure in a new language. *Proc. Natl. Acad. Sci. USA* 102: 2661–2665.
Savage SL and Au TK (1996) What word learners do when input contradicts the Mutual Exclusivity assumption. *Child Dev.* 67: 3120–3134.
Savage-Rumbaugh ES, Murphy J, Sevcik R, et al. (1993) *Language Comprehension in Ape and Child. Monographs of the Society of Research in Child Development*, serial no. 233, vol. 58(3–4). Chicago: University of Chicago Press.
Senghas A and Coppola M (2001) Children creating language: How Nicaraguan sign language acquired a spatial grammar. *Psychol. Sci.* 12: 323–328.
Senghas A, Sotaro K, and Özyürek A (2004) Children creating core properties of language: Evidence from an emerging sign language in Nicaragua. *Science* 305: 1779–1782.
Schafer G and Plunkett K (1998) Rapid word learning by 15-month-olds under tightly controlled conditions. *Child Dev.* 69: 309–320.
Schley S (1991) Infant discrimination of gestural classes: Perceptual precursors of ASL acquisition. *Sign Lang. Stud.* 20: 277–296.
Shaywitz BA, Shaywitz SE, Blachman BA, et al. (2004) Development of left occipitotemporal systems for skilled reading in children after a phonologically-based intervention. *Biol. Psychiatry* 55: 926–933.
Shi R and Werker JF (2003) The basis of preference for lexical words in 6-month-old infants. *Dev. Sci.* 6: 484–488.
Shipley EF, Smith CS, and Gleitman L (1969) A study in the acquisition of language: free responses to commands. *Language* 45: 322–342.
Slobin DI (1982) Universaland particular in the acquisition of language. In: Wanner E and Geitman LR (eds.) *Language Acquisition: The State of the Art*, pp. 128–170. Cambridge, MA: MIT Press.
Slomkowski C and Dunn J (1996) Young children's understanding of other peoples' beliefs and feelings and

their connected communication with friends. *Dev. Psychol.* 32: 442–447.
Smith CL (1979) Children's understanding of natural language hierarchies. *J. Exp. Child Psychol.* 27: 437–458.
Smith LB, Colunga E, and Yoshida H (2003) Making an ontology: Cross-linguistic evidence. In: Rakison D and Oakes L (eds.) *Early Category and Concept Development*, pp. 275–302. London: Oxford University Press.
Smith MA, Cottrell GW, and Anderson KL (2001) The early word catches the weights. *Adv Neural Inf. Process. System.* 13: 52–58.
Snyder L, Bates E, and Bretherton I (1981) Content and context in early lexical development. *J. Child Lang.* 8: 565–582.
Stern DN, Spieker S, Barneett RK, and MacKain K (1983) The prosody of maternal speech: Infant age and context related changes. *J. Child Lang.* 10: 1–15.
Stevens G (1999) Age at immigration and second language proficiency among foreign-born adults. *Lang. Soc.* 28: 555–578.
Stiles J (2000) Neural plasticity and cognitive development. *Dev. Neuropsychol.* 18: 237–272.
Swingley D (2005) 11-month-olds' knowledge of how familiar words sound. *Dev. Sci.* 8: 432–443.
Tallal P (2004) Improving language and literacy is a matter of time. *Nat. Rev. Neurosci.* 5: 1–9.
Tamis-LeMonda C, Bornstein M, and Baumwell L (2001) Maternal responsiveness and children's achievement of language milestones. *Child Dev.* 72: 748–767.
Terrace HS, Pettito LA, Sanders RJ, and Bever TG (1979) Can an ape create a sentence? *Science* 206: 891–900.
Thompson JR and Chapman R (1977) Who is 'Daddy' revisited: The status of two-year-olds' over-extended words in use and comprehension. *J. Child Lang.* 4: 359–375.
Tomasello M (1992) *First Verbs: A Case Study of Early Grammatical Development*. Cambridge: Cambridge University Press.
Tomasello M (1999) *The Cultural Origins of Human Cognition*. Cambridge: Harvard.
Trehub SE (1973) Infants' sensitivity to vowel and tonal contrasts. *Dev. Psychol.* 9: 91–96.
Trueswell JC, Sekerina I, Hill NM, and Logrip ML (1999) The kindergarten-path effect: studying on-line sentence processing in young children. *Cognition* 73: 89–143.
Valian V (1986) Syntactic categories in the speech of young children. *Dev. Psychol.* 22: 562–579.
Vargha-Khadem F, Watkins KE, and Price CJ, et al. (1998) Neural basis of an inherited speech and language disorder. *Proc. Natl. Acad. Sci. USA* 95: 2695–2700.
Vitevitch MS (1997) The neighborhood characteristics of malapropisms. *Lang. Speech* 40: 211–228.
Wales R, Colman M, and Pattison P (1983) How a thing is called: A study of mothers' and children's' naming. *J. Exp. Child Psychol.* 36: 1–17.
Waterman AH, Blades M, and Spencer C (2000) Do children try to answer nonsensical questions? *Br. J. Dev. Psychol.* 18: 211–225.
Waxman SR and Senghas A (1992) Relations among word meanings in early lexical development. *Dev. Psychol.* 28: 862–873.
Werker JF and Tees RC (1984) Cross-language speech perception: evidence for perceptual reorganization during the first year of life. *Infant Behav. Dev.* 7: 49–63.
Werker JF and Tees RC (1999) Influences on infant speech processing: Toward a new synthesis. *Annu. Rev. Psychol.* 50: 509–535.
White TG (1982) Naming practices, typicality, and underextension in child language. *J. Exp. Child Psychol.* 33: 324–346.
Windsor J (1999) Effect of semantic inconsistency on sentence grammaticality judgments for children with and without language-learning disabilities. *Lang. Test.* 16: 293–313.
Woodward AL, Markman EM, and Fitzsimmons CM (1994) Rapid word learning in 13- and 18-month-olds. *Dev. Psychol.* 30: 553–566.
Yuill N and Oakhill J (1991) *Children's Problems in Text Comprehension. An Experimental Investigation*. Cambridge: Cambridge University Press.
Zelazo PD, Frye D, and Rapus T (1996) An age related dissociation between knowing rules and using them. *Cogn. Dev.* 11: 37–63.
Zelazo PD, Müller U, Frye D, and Marcovitch S (2003) *The Development of Executive Function in Early Childhood.* Monographs of the Society for Research in Child Development, 68(3), serial no. 274. Oxford: Blackwell.

# 2.31 Transfer and Expertise: The Search for Identical Elements

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## 2.31.1 Introduction

Imagine you are traveling to London from the United States for the first time in your life. Having arrived at London's Heathrow Airport, you rent a car and take to the road. What is going to happen? The answer to this question is central to the issues treated in this chapter. In contrast to the United States, cars in England are driven on the left, rather than on the right side of the road. In addition, the driver's seat is on the right side of the car, and the stick shift is to the left of the driver. Thus, although the skills of driving a car in the United States and England share many common features, they are also quite different. One might ask, then, how well a person will be able to drive in England, assuming that the person has driven a car before in the United States. These questions address the issue of 'transfer.'

Transfer is always considered relative to a baseline condition. For example, one might ask how an experienced American driver compares to an experienced native English driver when driving in London. In all likelihood, the American driver will perform less well than the English driver, thus demonstrating less than perfect transfer from the American situation to the English situation. Alternatively, however, one might also ask how an experienced American driver compares to a novice English driver. In that case, the American driver will probably outperform the English driver, thus demonstrating 'positive' transfer from the American to the English situation.

According to a well-known definition by Ferguson, 'transfer' refers to

> any effects resulting from repetition, in the ability to perform a specified task, either the same task under different conditions or a different task. (Ferguson, 1954: 99)

Transfer is thus concerned with any effects that performing one task (original task) has on the subsequent performance of the same task under different circumstances or of a different task (transfer task).

Ferguson's definition of transfer makes it obvious that transfer is a very broad concept that relates to a large number of meaningful research questions. For example, does knowledge of Latin facilitate or impair the learning of mathematics? Or does listening to music by Mozart improve or not improve spatial reasoning? To get a better handle on the large variety of different questions and situations that transfer relates to, Perkins and Salomon (1992) suggested six dimensions that can be used to structure the domain of transfer: (1) positive versus negative transfer, (2) general versus specific transfer, (3) near versus far transfer, (4) vertical versus horizontal transfer, (5) literal versus figural transfer, and (6) low-road versus high-road transfer.

For example, transfer might be positive (facilitating) or negative (detrimental), and it might be general or specific. Transfer is positive if performing one task improves subsequent performance on a second task; transfer is negative when performing an original task leads to subsequent worse performance on the transfer task.

Transfer is said to be specific if only particular aspects of, rather than general attitudes toward, the original task affect the acquisition of a new task. In contrast, transfer is said to be general (or nonspecific) if it results from warm-up and learning-to-learn effects. Warm-up effects refer to the attainment of various sensory, postural, and attitudinal adjustments that are needed to tackle a task (e.g., adjusting eyes and head for proper viewing of items displayed on a computer screen, adapting to pacing conditions, etc.). These adjustments are usually made relatively early during task practice and, once made, need not be made again. Learning-to-learn refers to the attainment of general task procedures which, once activated, may then be applied to a subsequently encountered task situation. Examples include skill in detecting stimuli on a computer screen and discovering procedures that ease a mental calculation task. As will become evident later, in current information-processing theories the distinction between general and specific transfer is increasingly difficult to maintain. Different types of transfer (i.e., positive and negative transfer, or general and specific transfer, or near and far transfer) may well occur together, as when certain aspects of the original task facilitate the acquisition of the new task while other aspects hinder it.

As a psychological topic, 'transfer' has both a long and a controversial history. Theoretical discussions of transfer can be traced back to at least the early writings of Greek philosophers, such as Aristotle and Plato. At the time, transfer was an important concept because it helped to explain why a mind that was born blank (i.e., blank slate) was nevertheless capable of acquiring knowledge from the beginnings of its existence (c.f., the later writings of British Empiricists, such as Locke and Reid).

More recently, transfer has become a highly controversial topic for at least two different reasons: empirical and theoretical. Empirically, so-called 'far' transfer, that is transfer across conceptually different domains, has been notoriously difficult to obtain. Consequently, some theorists (e.g., Detterman, 1993) have even argued that transfer, at least transfer that has any practical implications, does not exist (but see, e.g., Halpern, 1998; Barnett and Ceci, 2002).

Theoretically, different conceptualizations of how the human 'mind' works have tended to foster radically different and incompatible views on the mechanisms underlying transfer that have been heatedly debated over the course of the past 100 years. To understand this point, it is necessary to realize that transfer is a higher-order phenomenon. That is, to explain transfer one need not only describe the mechanisms by which transfer is achieved but also the mechanisms underlying performance and learning in the two tasks between which transfer occurs. In other words, the theoretical explanation of how original and transfer tasks are learned and are performed constrains the theoretically possible explanations of how transfer is achieved.

## 2.31.2 Goals and Structure of the Chapter

In many contemporary texts on transfer, the main focus is on summarizing empirical findings that elucidate the conditions that lead or do not lead to different types of transfer. Thus, for example, it may be argued that transfer is affected by two classes of variables that relate to (1) the encoding of the original task, and (2) the retrieval of the transfer task. Variables affecting transfer via the encoding of the original task are, among many others, (1) the degree of learning of the original task, (2) the differential use of learning strategies, (3) the number and variability of shown examples, and (4) abstract training. Variables that affect transfer by increasing or decreasing the likelihood that a transfer task is retrieved include (5) the similarity of surface and structural components of the original and transfer tasks, (6) the similarity of processing in the two tasks, as well as (6) the provision of hints (for an excellent recent summary of the variables that have empirically been shown to affect transfer, see, for instance, Kimball and Holyoak, 2000).

In contrast to this empirical focus, the focus of the present chapter is primarily theoretical. That is, our main focus is on discussing some of the most important theoretical conceptions of transfer that have been offered in the past 100 years. Empirical data are described only to the extent that they further understanding of the theoretical conceptions. There are two reasons for why we focus on theories rather than on empirical findings. First, there already exists a number of excellent recent summaries of empirical research on transfer (e.g., Kimball and Holyoak, 2000), and little is gained by providing yet another summary chapter. Second, we strongly believe that the results of empirical research on transfer can only be understood in the context of a firm and clear theory, and that a deep and thorough understanding of transfer is more likely to result from a discussion of theories than from a summary of empirical research findings.

The chapter has thus two goals. Our first and main goal is to present an overview of important theories of transfer that have been developed in the past 100 years. By comparing older with more recent theories, it will become very obvious in which way and why our understanding of transfer has changed, and where we are currently heading.

Our second goal is to discuss the relation between transfer and expertise, that is, the question of whether or not expertise in any given domain modulates transfer. Although perhaps surprising at first glance, this specific question is a natural consequence of our statement that transfer can only be understood in the context of performance and learning theories. If indeed an understanding of how tasks are performed and are learned in the first place necessarily precedes the formulation of a transfer theory, then it is at least not unreasonable to suspect that transfer might be qualitatively different at the beginning and advanced stages of learning.

We begin with a brief overview of the two most important theories on transfer that existed at the beginning of the twentieth century: the Doctrine of Formal Discipline and the Theory of Identical Elements. Second, we discuss, in some detail, transfer theories that are based on the notion of 'identical elements.' Not surprisingly, we show that what has been termed 'identical elements' varies widely across theories. Intertwined with the description of the transfer theories, we discuss the relation between transfer and expertise. Next, we return to the original idea of the Doctrine of Formal Discipline and argue that derivates of this idea are still heatedly debated in present-day psychology. Finally, we briefly summarize the current state of affairs and offer some conclusions.

## 2.31.3 Transfer Theories at the Beginning of the Twentieth Century

One of the first theories of transfer that not only was taken seriously by philosophers of mind but was widely applied to school settings as well has come to be known as the Doctrine of Formal Discipline (Locke, 1693). The Doctrine of Formal Discipline was based on a meta-theory of the human mind according to which the mind is divided into a number of general faculties, such as attention, reasoning, and memory (faculty psychology). Each faculty can be likened to a muscle that can be trained in a variety of ways. Improved muscle strength (e.g., improved reasoning ability) then benefits all mental tasks that require the specific muscle or faculty. Thus, studying mathematical problems, for example, not only improves mathematical ability but also philosophical thinking – at least to the extent that the two subject areas require the same reasoning faculty. Studying subjects such as Latin and geometry, therefore, is of pedagogical value because it serves to 'discipline' the mind.

The theory was literally uncontested for many years; Thorndike and Woodworth (1901a,b,c) were the first to provide strong empirical evidence against the Doctrine of Formal Discipline. In one of their experimental situations, for instance, they had participants estimate the areas of different-sized shapes and found little evidence of transfer of estimation from one shape to another. The mind, they concluded (Thorndike and Woodworth, 1901a: 248) is "a machine for making particular reactions to particular situations," and "spread of practice occurs only where identical elements are concerned in the influencing and influenced function" (Thorndike and Woodworth, 1901a: 249). With their Theory of Identical Elements, Thorndike and Woodworth proposed one of the most durable theories of transfer, which laid the groundwork for most of the empirical and theoretical work that was to follow later.

Although the Theory of Identical Elements rapidly emerged as the most widely accepted principle describing transfer in the early years of the century and was believed to account for most of the available transfer data (e.g., Hunter, 1929; McGeoch, 1942), it was by no means without its critics. Orata (1928), for instance, criticized the Theory of Identical Elements for its inability to explain findings reported by Judd (1908) and proposed a mental model theory of transfer instead (for more recent elaborations on this topic see, for instance, Kieras and Bovair, 1984). In his study, Judd had two groups of primary schoolchildren throw darts at an underwater target. Only one of the groups had the principle of refraction explained to them. The groups performed equally well at the start when the target was submerged 30.5 cm. However, when the target depth was changed to 10 cm, the group that knew the principle of refraction performed better. Furthermore, there was no transfer from 30.5 to 10 cm in the group that did not have the principle of refraction explained. Although the actual group differences obtained were rather small, the pattern of this finding was later replicated by Hendrickson and Schroeder (1941).

At least part of the reason why Thorndike and Woodworth's Theory of Identical Elements has been so tremendously successful was that the theory was, on the one hand, general enough to cover many different task situations while, on the other hand, not too general to still be meaningful. The theory was really more a general framework than a specific model. What it was lacking (very obviously) was a clear definition of what 'identical elements' were, or even more basic, what the elements were in the two tasks or two skills between which transfer was to occur.

In the next section, we summarize historical and recent ideas on what 'identical elements' are. Most of the ideas have come out of the verbal learning and the information-processing traditions, which will be addressed in turn.

### 2.31.3.1 Verbal Learning Tradition

The domain of verbal learning has been one of the most carefully and thoroughly studied areas in modern psychology and, consequently, has generated a vast amount of theoretical and empirical information. For illustrative purposes, we begin our discussion in the area of serial verbal learning.

The objective in serial verbal learning is to learn a list of serially arranged words such that the list can be reproduced (in correct order) at a later point in time. The method of serial verbal learning was introduced by Ebbinghaus (1885) who arranged artificial verbal materials (nonsense syllables) into serial lists and read them to the beat of a metronome until they seemed just on the verge of being learned; then, he would look away from the sheet on which the list was printed, and would try to recite the list. Ebbinghaus's measure of learning was the amount of time it took him to learn the entire list; his measure of transfer was the percentage of time saved in relearning the same or similar lists.

### 2.31.3.2 Serial Learning Analysis

Ebbinghaus was not only the first to introduce the empirical method of serial verbal learning, but also the first to construct a theory for what is actually learned in serial verbal learning (Ebbinghaus, 1885). His theory was based on the ideas of British Associationists such as David Hume (1739/2000) and John Locke (1693). According to British Associationists, learning is viewed as the acquisition of connections, or associations, between the stimulus (S) and response (R) units that are indigenous to a given task. The basic requirements for the acquisition of associations are that the to-be-related S unit and R unit occur contiguously, that their contiguous occurrence be repeated, and that the evocation of the R unit be followed by some reinforcing event.

The basic principle of serial learning, according to Ebbinghaus, is that every item in a list of serially presented verbal items becomes associated with every other item, subject to two qualifications: First, the strength of an association between two list items varies inversely with their degree of remoteness, that is, with how far apart they are in the series. Second, forward associations, for any particular degree of remoteness, are stronger than backward associations. From these qualifications it appears that the basic mechanism that permits learning of a serial ordering is the formation of associations linking adjacent items in the forward direction. This chaining hypothesis was hardly considered hypothetical at all; it was almost self-evidently true to researchers between the time of Ebbinghaus and the late 1950s.

Given that Ebbinghaus's ideas of serial verbal learning were almost uncritically accepted until at least the late 1950s, it is clear that most theories of transfer of verbal learning during this period had to be, and in fact were, based upon the concept of forward associations. If what was learned in serial learning were primarily the forward associations, then these associations had to be the identical elements, the basic components proposed by Thorndike and Woodworth that were to be transferred to a new task. Early evidence for this claim came from Ebbinghaus's own research with derived lists.

A derived list is one that contains the same items as a list learned earlier, but in an order that is altered in some prescribed, meaningful manner. These orders can be arranged such that associations of varying degrees of remoteness, forward or backward, are presumed to transfer from the original list to the learning of the second, derived list. A forward first-order derived list, for instance, is one formed by skipping one item in constructing the new list; thus the original list A-B-C-D-E-. . .-K yields the forward first-order list A-C-E-. . .-K. Similarly, second-order, third-order, etc., lists can be formed by skipping two items, three items, etc.

The derived list method offered Ebbinghaus a potent means for testing the validity of his theory. Specifically, he constructed a number of transfer lists having first-, second-, third-, and seventh-order degrees of forward remoteness. For each of these derived lists, he had learned the original list 24 h earlier. The results of the experiment were expressed as savings – how much more rapidly it was possible to learn the derived lists than the corresponding original lists – and confirmed the predictions of Ebbinghaus's theory: all conditions with regularly derived lists resulted in more savings than a random-order control condition. Furthermore, the closer the remote associations being transferred, the greater the savings.

Ebbinghaus's original derived list experiments were later harshly criticized on methodological grounds. The most serious concern was an objection raised by Slamecka (1964) to the procedure of skipping a regular number of items when deriving the second lists. Slamecka noted that with a regularity of this sort, participants might discover the rule for derivation and use the first list to mediate acquisition of the second, derived, list. In one of his own experiments, Slamecka (1964) compared the Ebbinghaus procedure with one in which the average degree of remoteness on a derived list was fixed, but the number of items skipped was variable. With this new procedure, Slamecka did not find positive transfer from the first to derived lists.

As a result of these and other criticisms, theorists became increasingly convinced that the serial methodology was not the method of choice for empirical work on transfer of learning and needed to be replaced with paired-associate learning. Although a stimulus-response analysis of learning was almost universally accepted at that time, with each item in the list serving both as a stimulus for the next item and as a response for the previous item, the stimuli and responses could not be manipulated independently of one another in an experiment. With paired-associate learning, however, stimulus and response similarity could easily be manipulated independently. Paired-associate learning, therefore, quickly became the method of choice for scientists working on theories of transfer.

### 2.31.3.3 Paired-Associate Analysis

#### *2.31.3.3.1 One-component models*

In paired-associate learning experiments, participants are asked to learn two paired-associate lists, one after the other. Of interest is the relation between the two lists in terms of which learning can be applied from the first to the second list. Using an alphabetic code, one may represent various transfer situations by a double pair where the first pair, A-B, denotes the first list, and the second pair denotes the second list. For example, in the A-B, A-D paradigm, the second list has the same stimulus units, A, as the first list, but different response units, D; that is, one must learn to make different responses on the second list in the presence of familiar stimuli. In the A-B, C-B paradigm, in contrast, one must make familiar responses in the presence of new stimulus units. The A-B, C-D paradigm is often considered to be a baseline, or control, paradigm because there is no deliberate similarity relation between the two lists, and duration of practice is typically identical for the two conditions.

Most of the original work on transfer of paired-associate learning, culminating in Osgood's (1949) transfer surface, described in the paragraphs that follow, was based upon the same theoretical framework that Ebbinghaus's model of serial verbal learning was based upon, namely, classical S-R theory. Consequently, transfer was explained in terms of the similarities of the S-to-R associations acquired in the context of Task 1 and Task 2. According to the logic of classical S-R theory, transfer between the tasks can be experimentally manipulated by varying

(1) the similarity between the S units of Task 1 and Task 2, (2) the similarity between the R units of Task 1 and Task 2, and (3) both the similarities between the S units and the R units in Task 1 and Task 2 simultaneously and independently.

To illustrate, let us consider the situation in which stimulus (S) similarity is varied (from A to A′ to A″; the prime indicates the decreasing similarity) and responses (R) are kept identical. In this case, associative strength from a given S-R pair of Task 1 is said to generalize to its Task 2 counterpart that maintains the same R unit. The extent of the generalization is dependent upon the degree of similarity between the S unit of Task 1 and the S unit of Task 2 and decreases monotonically with decreasing similarity. The underlying mechanism of transfer is said to be stimulus generalization.

Classical transfer theory predicts optimal positive transfer for the A-B, A-B paradigm, in which both stimulus and response are kept identical in Task 1 and Task 2; high positive transfer for the A-B, A′-B paradigm, in which the stimulus unit of Task 2 is closely related to the stimulus unit of Task 1; less positive transfer for the A-B, A″-B paradigm; and no transfer for the A-B, C-B paradigm. Transfer research has provided substantial support for most of these predictions. Positive transfer has been the usual outcome for the A-B, A′-B paradigm (for instance, Dallett, 1962), and the amount of positive transfer appears to decrease with decreasing intertask similarity between the S units (Dallett, 1962; Brown et al., 1966).

Most of the existing data on paired-associate transfer were summarized by Osgood (1949) in his transfer and retroaction surface (the term 'retroaction' refers to retroactive inhibition, the effect a second task can have in impairing retention of a first task). This three-dimensional graph, depicted in **Figure 1**, shows how much transfer there is to be expected between two tasks as a function of how similar they are in terms of their stimulus and response units. Assuming a constant first list, A-B, the various points on the graph show how much transfer is to be expected with different second lists. For example, if the second list is identical to the first, the A-B, A-B paradigm, there will be high positive transfer. If the stimulus units remain the same but require entirely new responses, as is true in the A-B, A-D paradigm, negative transfer results.

Several studies (e.g., Dallett, 1962; Wimer, 1963) have examined a fair sample of all the possible relations within the transfer surface. As one might expect,

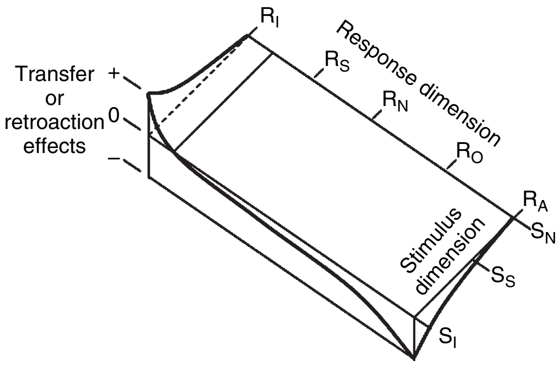


**Figure 1** Osgood's transfer and retroaction surface. Note that the medial plane represents transfer effects of zero magnitude. Response relations are distributed along the length of solid and stimulus relations along its width. Adapted from Osgood CE (1949) The similarity paradox in human learning: A resolution. *Psychol. Rev.* 56: 132–143, with permission from Elsevier.

these experiments were rather large and complicated. One of them (Wimer, 1963), for instance, combined five degrees of stimulus similarity between tasks with five conditions of response similarity. In general, the broad outcomes of these studies are in agreement with each other and with the predictions of the Osgood surface.

Although classical S-R theory has been quite successful in predicting transfer for situations in which the similarity of S units and/or R units was manipulated between tasks, it has been much less successful in predicting transfer in a situation in which the S units of Task 1 are unrelated to the S units of Task 2 while the R units are still identical (A-B, C-B paradigm). Classical S-R theory predicts no transfer in this case. However, Twedt and Underwood (1959) found a trend toward negative transfer, and other investigators have found significant amounts of negative transfer (e.g., Kausler and Kanotti, 1963).

Furthermore, reasonably good success in explaining the direction and magnitude of transfer has been shown only for the paradigms the theory is equipped to handle. Excluded from consideration, for instance, are paradigms that fall outside these boundaries, such as the A-B, B-C paradigm, for which slight negative transfer has been repeatedly found (e.g., Murdock, 1958; Goulet and Barclay, 1965). Thus, in order to explain all possible transfer conditions, rather than only a few, classical S-R theory had to be expanded into what have been labeled multi-component theories.

#### 2.31.3.3.2 *Multi-component models*

In multi-component models, it is assumed that the learning of paired-associate lists, and in general of any material, is a result not only of forward associative learning but also of backward associative learning, response learning, and stimulus learning (Martin, 1965; Kausler, 1966). Consequently, transfer may not only affect the acquisition of Task 2 forward associations but also any other of the proposed components. It should be clear that the addition of components, although not altering the basic logic of transfer, considerably complicates the analysis of transfer in paired-associate learning.

The direction and amount of overall transfer are now the combined result of the separate component effects. If negative transfer occurs for one component and zero transfer for all other components, then the overall transfer effect would necessarily be negative. However, if a second component contributes positive transfer, then the negative effect of the first component is diminished. Thus, predictions concerning overall transfer are based on the consideration of the specific effects of the separate components, with the amount of overall transfer simply being the algebraic sum of the amounts of transfer contributed by the separate components.

It should also become clear that the multi-component view of transfer is not compatible with Osgood's (1949) summary of transfer phenomena. Osgood's analysis is limited to situations in which learning consists only of acquiring the forward associative component. That is, Osgood's original transfer surface does not take into account familiarity with stimuli and/or responses. (Without going into details, we just briefly note that, in response to these problems, Martin (1965) called for a modification of Osgood's original transfer surface and proposed, instead, three different surfaces, one for each of three different components of transfer, namely, response learning, forward associations, and backward associations.)

### 2.31.3.4 Transfer and Expertise: Effects of First-Task Practice on Transfer of Paired-Associate Learning

In verbal learning theories of transfer, at least two different questions address the relation between transfer and expertise. First, one might wonder whether or not, in general, expertise facilitates or hinders transfer. That is, are experts 'better' or 'worse' at transfer both within and outside of their domain of expertise? To some extent, the answer to this question is trivial. Assuming that experts possess more knowledge in their domain than do nonexperts, they have, in terms of verbal learning theory, more stimulus representations, more response representations, and more associations at their disposal to transfer to a different task. Thus, they should be at an advantage in any situation that is similar to the situation they are expert at.

The question regarding potential benefits and costs of expertise, however, inevitably leads to a much more specific and theoretically much more compelling and important second possible question concerning the relation between transfer and expertise. In behaviorist single-component and multi-component views of transfer, this question boils down to how familiarity with or practice on the first task affects the content of transfer. That is, does expertise modulate what is transferred between two tasks? In multi-component views, this question can be much more complex and more difficult to disentangle than in the classical one-component approach. In classical S-R theory, to become more familiar with a task simply means that the forward associations grow stronger. Thus, familiarity with the first task enhances the effects of transfer, negative or positive, by increasing the strengths of S-to-R forward associations.

In multi-component approaches, however, the effects of familiarity can be selective; that is, the effects of familiarity can strengthen some components while not affecting others and vice versa. This added possibility makes research on first-task practice an elegant tool for testing the validity of multi-component views. Thus, prepracticing the stimuli but not the responses, for instance, will tend to make the stimuli more readily available for retrieval, but will not – or only minimally – affect the strength of the associations and the availability of responses. That is, by way of experimentally inducing familiarity with some components but not with others, the multi-component view of learning can be experimentally tested. Consequently, most of the studies in which practice on the first task was varied were primarily interested in proving their version of a multi-component learning theory, rather than in addressing the issue of whether the basic components of transfer change with practice on the first task. Nevertheless, these studies have provided some interesting insights and are briefly discussed.

Experimental studies on the effects of first-task practice on the acquisition of a second task can be classified in the following way: (1) studies in which only the response units of Task 2 received practice in Task 1 (basically an A-B, C-B paradigm), and (2) studies in which only the stimulus terms of the second task were practiced in Task 1 (basically an A-B, A-C paradigm).

For example, as Martin (1965) points out, multicomponent views explain transfer in the A-B, C-B paradigm as depending largely on two factors: negative transfer due to backward interference and positive transfer due to response availability. Thus, with a low degree of practice, the strength of B-to-A (backward) associations carried over as the source of interference for the B-to-C associations should be relatively slight. On the other hand, even with a low degree of practice, response learning of the B units should be fairly complete by the end of Task 1 practice. Assuming the B units are of low meaningfulness (to avoid further complications), the positive transfer from response learning is likely to outweigh the slight negative transfer from associative learning, thereby yielding slight overall positive transfer.

With a high degree of Task 1 practice, however, the strength accrued for B-to-A associations should be sufficient to assure strong interference with the B-to-C associations. The negative transfer from backward associative learning should now outweigh the positive transfer from response learning (which is unlikely to increase beyond the amount manifested with a low degree of Task 1 practice), leading to overall negative transfer.

This balance of forces was nicely illustrated in a study by Jung (1962), in which he showed that with a low degree of Task 1 practice there was a trend toward positive transfer, while with a high degree of Task 1 practice the trend shifted to negative transfer. Similar results were obtained in a study by Schulz and Martin (1964) in which familiarity with Task 1 response units was achieved not via amount of practice but via degree of response meaningfulness.

It appears then that within the framework of multi-component views of transfer, the effects of Task 1 practice on the performance of Task 2 can be readily explained by introducing a strengthening mechanism: With practice, stimuli and responses become more easily available and associations become stronger. Importantly, the components of transfer do not appear to change with practice at all. Instead, what changes with practice is simply the strength or availability of transfer components, but not the nature of transfer.

## 2.31.4 Information-Processing Theories

Most of the theoretical positions we review next (Johnson; Kieras, Polson, and Bovair; Singley and Anderson), although differing on the specifics, share a common assumption: The acquisition of a task consists of separate learning stages that result in a multilevel hierarchy of organization. The basic idea conveyed by this hierarchy, and the one that fundamentally sets these new theories apart from earlier stimulus-response views, is that higher-level units are not simply associations of lower-level units, but are functionally distinct from lower-level units and can be accessed and used independently.

Two groups of nested-hierarchy theories differ on how this hierarchical organization comes about and in how it is used. The 'nonassociative recoding' position (Crowder, 1976), first articulated by researchers like Jensen, Bower (e.g., Trabasso and Bower, 1968), and Johnson (1969), relies primarily on information-processing machinery; the 'multilevel-associative' positions of Hebb (1961) and Estes (1972) stay within the associations-through-temporal-contiguity framework, but escape the limitations of the approach.

In the following, we concentrate on the 'nonassociative recoding' positions simply because their development has led directly to the modern conceptions of transfer. Starting with Johnson's classic coding theory, we then turn to the more recent approaches taken by Kieras, Polson, and Bovair, and by Singley and Anderson.

### 2.31.4.1 Johnson's Coding Theory

Although originally developed to explain recall of sentences, Johnson's coding theory (Johnson, 1969, 1970, 1972, 1978) presents a rather elaborate model of how the process of grouping lower-level knowledge units into higher-level units is established during learning and how higher-order units are used in task performance. Coding theory is based upon the concept of recoding that was originally developed by Miller (1956). Miller proposed that when participants are presented with items that are to be remembered, they can increase their recall by recoding subsets of items into higher-order units.

Johnson calls the memorial representation of a collection of items that are grouped together a 'code.' The specifics of coding theory can be summarized in the following five points. First, the main theoretical property of codes is that they are unitary. They are single memory devices that can represent a number of individual items (i.e., memorial representation of a group of items). Because codes are unitary, they are recovered from memory in an all-or-none fashion; that is, once a code is recovered, all the information the code represents is recovered.

Second, codes are distinct from the information they represent. This distinction between code and content is analogous to the one often made between a category and the items from the category.

Third, an important implication of this distinction is that codes may be viewed as if they were opaque containers. That is, if the code and the represented information are distinct, then the recall of codes might be largely independent of the recall of the information represented by the code. For example, a participant might feel confident that she can remember a free-recall list because she remembers that it contained instances of birds, trees, and flowers. However, at the time of recall, she might discover that when she attempts to decode the category labels into their appropriate instances she is unable to remember the exact items that appeared in the list.

Fourth, codes can represent either individual items or other codes. Hierarchical coding occurs when the codes at one level of organization are recoded into higher-level codes. Note that any given set of items can be recoded into very different organizations. The sequence SBJFQLZ, for instance, could be organized by including SBJ in one chunk, FQLZ in another, and then recoding the codes for those two chunks into one higher-order code representing the entire sequence. Alternatively, the sequence could be organized into codes for three lower-order chunks like SB, JFQ, and LZ, and then the codes for these three chunks could be recoded into a code representing the entire sequence. For any given set of items, there exist many different organizations that can be imposed.

Finally, to allow for correct sequential retrieval of codes and items within codes, Johnson assumes that codes at any given level in the hierarchy and items within codes are distinguished by order tags.

The implications of Johnson's coding theory for an understanding of transfer should be fairly obvious. If learning a task is equivalent to learning a hierarchy of codes, rather than to learning a series of forward or backward associations, then codes, rather than associations, should be the identical elements, the components of transfer. Furthermore, what changes with practice and expertise is not simply the strength or availability of components, as in S-R, associative views, but the nature of the components themselves. With practice, lower-level codes will be recoded into functionally distinct higher-level codes.

Bower and Winzenz (1969) directly compared the S-R associative view of transfer with the code-based view in a study in which they repeatedly gave participants the same series of letter sequences. The Bower and Winzenz study was basically a replication of experiments by Hebb (1961) and Melton (1963) that had shown that the recall of a letter sequence was improved if it was repeated later in the session. Bower and Winzenz were able to show that this improvement from repetition occurred only if a sequence was grouped in the same way on both occasions. For example, if the series ABCDEFG was presented once with rhythmic grouping AB′CDE′FG and then later again with the grouping changed to ABC′DEF′G, then there was no improvement. However, if the same rhythmic breakdown was used on both occasions, then there was a gain from the first to the second trial.

Bower and Springston (1970) tested the same idea with prior experience from semantic, as opposed to episodic, memory. In their study, participants were asked to recall 12-letter strings that were broken into groups by pauses within the string. In some cases, the strings were broken by pauses so as to coincide with familiar acronyms, e.g., TV-IBM-TWA-USSR; but in other cases, the pauses did not coincide, e.g., TVI-BMTW-AU-SSR. Bower and Springston found that the facilitation occasioned by familiar acronyms was heavily dependent on whether the presented grouping corresponded with the acronym boundaries or not.

Note that in the Bower and Winzenz and Bower and Springston studies, the materials to be transferred from Task 1 to Task 2 were absolutely identical. That is, the effects reported could only be due to the differences in the organization of the materials. These studies, then, seem to demonstrate that codes, as defined by rhythmic grouping, rather than forward or backward associations, are transferred from one task to another. In a whole series of similar studies, Johnson and associates explored the role of codes in transfer of learning more systematically.

For instance, Johnson (1969, 1970) asked participants to learn a sequence of grouped letter triplets, such as SBJ′FQL′ZNG. Following the first-list learning, they were asked to learn another list that was identical to the first except that one letter in each of two groups was changed (e.g., SBJ′FQL′ZNG changed to ′SXJ′FQL′TNG). After learning the second list, participants were asked to recall the first list.

The results of these experiments showed that the loss for the unchanged letters from a group with a change was about 50% relative to a rest control condition (no second list), whereas the loss of the unchanged letters in groups without changes was about 10% or less. These findings are consistent with Johnson's coding theory and do not seem to be readily explainable by an S-R–based associative view of transfer.

Note that the coding view also predicts that the amount of transfer is not affected by which particular letter in a group is changed and also that the number of letters changed in a group should have no relation to the amount of transfer. That is, if a middle letter from a group is changed, transfer is no different than if the first or the last letter is changed. Furthermore, whether one, two, or three letters in a group are changed should not affect transfer, either. Both of these predictions have been confirmed experimentally (Johnson, 1970).

These and similar experiments provide rather strong evidence for the view that codes, rather than associations, are the basic elements of transfer. Unfortunately, the effects of practice on transfer have never been experimentally explored. With practice, the theory assumes, functionally distinct higher-order codes are formed from lower-order codes. Therefore, the components of transfer are predicted to change. One reasonable assumption to make would be, for instance, that what is transferred from one task to another are only the (reusable) codes at the highest possible level of hierarchy, an interesting and also experimentally testable prediction.

The appraisal of Johnson's coding theory depends on what criteria one decides to apply. Johnson's accomplishments seem very impressive if one looks at those aspects of the theory that relate to the explanation and prediction of transfer phenomena. The experimental effects associated with the theory are both clear-cut and nonintuitive. However, Estes (1972), for instance, has complained with complete justification that, despite Johnson's (1978) later elaborations, the theory is primarily a metatheory. That is, it leaves many of the most fundamental processes – sequential retrieval, coding mechanisms, decoding mechanisms – underspecified.

One could argue that at least one of the reasons why the mechanisms of coding theory are relatively unexplored may have been the fact that information-processing machinery only later, with the introduction of production-system architectures, has developed the tools for a full-fledged process analysis. Next, we describe two recent information-processing approaches to transfer that, although different in their theoretical conceptualizations, are both implemented in a production-system architecture. Therefore, it will be useful to briefly describe the general properties of a production system.

### 2.31.4.2 An Overview of Production-System Models

Production systems have become an almost generic theoretical formalism in cognitive psychology. Numerous production-system models of cognitive processes have been developed. Examples include problem-solving models (Newell and Simon, 1972; Karat, 1983), models of text comprehension (Kieras, 1982), and models of learning (Anderson, 1982).

In general, production systems represent knowledge as a collection of rules. Processing mechanisms interpret these rules, thereby generating a sequence of cognitive operations and actions. In its most fundamental form, a production system consists of two data structures, a long-term declarative memory of facts and a production memory, that are connected through a processing cycle. The production memory can be described as a collection of IF-THEN condition-action rules (productions) of the form

IF (condition) THEN (action)

The processing cycle works as a three-stage recognize-act cycle. It matches the IF parts of one or more production rules (from production memory) with the contents of some active part of the declarative memory (often referred to as short-term memory or working memory), decides which of the matched rules to fire (conflict resolution), and executes the THEN part of the selected rules, resulting in either the activation, modification, or execution of an existing memory structure.

Note that the condition part of a production rule can contain information at very different levels of abstraction. For example, it might contain current goals or subgoals or information about the external task environment.

Production systems are usually hierarchically organized and goal-driven. That is, a sequence of production rules is organized such that the system moves from satisfying one subgoal to satisfying another subgoal to satisfying a general goal and so on. This sequential, goal-driven behavior is modeled by having the production rule that just fired delete the subgoal accomplished and add a new subgoal to working memory. The sequential behavior of the model is, thus, controlled by manipulating the pattern of subgoals.

Next, we turn to two information-processing approaches that make direct use of the production-system formalism in their formulations of transfer theories. Both of these theories assume that production rules, rather than associations or codes, are the identical elements of transfer. Beyond this commonality, however, the two theories differ fundamentally.

### 2.31.4.3 Kieras, Polson, and Bovair's Theory of Transfer

Perhaps the simplest and most straightforward approach that any theory implemented in a production-system environment could take with regard to explaining transfer is the one taken by Kieras, Polson, and Bovair (e.g., Polson and Kieras, 1984, 1985; Kieras and Polson, 1985; Kieras and Bovair, 1986; Polson, 1987). Very much unlike the theories described so far, Kieras, Polson, and Bovair's approach to understanding transfer is not based upon a learning theory. Instead, these researchers, in essence, construct production systems for each of the two tasks involved in transfer, the original and the transfer task, and then examine them for the amount of production overlap by simply counting the number of productions that appear in both systems. The more productions the two tasks have in common, the greater the amount of transfer. Thus, according to this view, production rules are the identical elements of transfer that were postulated by Thorndike and Woodworth.

Production rules are transferred from one task to another if they are either identical or generalizable. They are identical if they have the same conditions and the same actions; they are generalizable when a condition can be derived from other conditions by replacing a constant with a variable. In fact, Kieras and Bovair (1986), for instance, note that in all their analyses of transfer, generalizations and identical rules were transferred equally quickly and were learned much faster than new production rules.

Note that transfer, in Kieras, Polson, and Bovair's view, is simply a matter of reusing old production rules in a new context. The model is simple and straightforward because it is based upon an essentially static representation of knowledge. All that is needed to predict amount and direction of transfer from one task to another is to construct two production systems that model task performances in the two tasks and to count the number of identical and generalizable production rules. Kieras, Polson, and Bovair take this approach even further by keeping the production systems they generate as simple as possible. As Kieras and Polson state, their production system is the

> . . . most elementary form of production system in that there are no conflict resolution rules, and very simple kinds of pattern matching are used in evaluating conditions. (Polson and Kieras, 1985: 207)

Likewise, they make no attempt to represent fundamental cognitive processes, such as memory retrieval or reading comprehension, and assume that each production takes the same amount of time to execute.

Note that, despite its simplicity, the identical-production-rules view of transfer has a clear advantage over classical associative theories of transfer: Productions are abstract entities that can be used to describe human behavior at different levels of abstractions. In associative models, stimuli and responses describe mostly overt behavior. Production rules, in contrast, can represent higher-order and lower-order goals as well as externally observable behavior or rule-based reasoning, etc. That is, they can be used to represent many different entities at various levels of generality. Thus, production rules are extremely flexible with regard to what they can represent.

Kieras, Polson, and Bovair have experimentally tested their model of transfer in various studies and in two different domains, namely, text editing (e.g., Polson and Kieras, 1985; Polson, 1987; Polson et al., 1987) and operating a simple device (e.g., Kieras and Bovair, 1986). The results of these studies demonstrate very clearly that production rules can, in fact, provide a very useful characterization of what is transferred from one task to another.

Kieras, Polson, and Bovair's approach to understanding transfer is best described as a cognitive engineering approach (Gray and Orasanu, 1987). As a general theory of transfer, however, the belief that the amount of transfer can be determined by simply counting productions can be criticized for at least two different reasons. First, production rules might differ with regard to how important they are in a particular system. Foss and DeRidder (1987) argue that productions that are higher up in the goal structure of a particular task might be more important for transfer than productions at a very 'late' level in the goal structure. Thus, a change in the syntax between old and new systems may result in a substantial number of differences in the production rules that describe the behavior of the user, but if all these changes are 'late' in the goal structure, then they might not have the same impact on transfer as an equal number of changes in production rules that affect subgoals 'higher' in the goal hierarchy.

The second criticism that can be leveled against counting identical production rules is the one mentioned already, namely, the fact that this theory – because it is not closely tied to a learning theory – completely ignores the level of skill at which the original task is performed.

Both of these criticisms have been addressed in a theory of transfer that was formulated by Singley and Anderson (1985, 1989). These authors propose essentially an extension to Kieras, Polson, and Bovair's view of transfer that is heavily dependent upon Anderson's theory of learning (Anderson, 1982, 1983, 1986, 1987).

#### 2.31.4.4 Singley and Anderson's Theory of Transfer

Like Kieras, Polson, and Bovair, Singley and Anderson (1985, 1989) propose that production rules are the common elements that are transferred from one task to another. Unlike Kieras, Polson, and Bovair, however, and very much in line with the theories discussed earlier, their view is based upon a powerful learning mechanism, implemented in Anderson's Adaptive Control of Thoughts (ACT*) theory of human cognition. In this learning mechanism,

> . . . knowledge comes in declarative form, is used by weak methods to generate problem solutions, and as a by-product, new productions are formed. The key step is the knowledge compilation process, which produces the domain-specific skill. (Singley and Anderson, 1989: 50)

This statement is central to ACT*'s account of learning. The theory breaks down the acquisition of skill into two major stages: a declarative stage, where a declarative representation of the skill is interpreted by general, nonspecific, problem-solving productions (such as analogy, means-ends analysis, pure forward search, etc.), and a procedural stage, where the skill is directly embodied in domain-specific productions. The transition from the declarative to the procedural stage is achieved by the process of knowledge compilation. Knowledge compilation consists of two separate mechanisms: the composition mechanism collapses sequences of general productions into a smaller number of highly specific productions (larger IF parts), and the proceduralization mechanism deposits domain knowledge from long-term memory directly into productions.

The initial use of weak methods and knowledge compilation are the main factors that influence the acquisition of domain-specific productions. However, two additional factors influence their execution, namely, strength accrual and working memory limitations.

The strength of a production determines how rapidly it applies. Production rules accumulate strength as they successfully apply; that is, as they are practiced and learned. Just as learning has an impact on production strength, it has an impact on working memory limitations; that is, working memory increases with practice. Because in ACT*, the only way errors can occur is through the loss of information in working memory (leading to the wrong production firing or the correct production firing but producing the wrong result), an increase in working memory will tend to decrease the likelihood of errors occurring.

Singley and Anderson's theory of transfer differs from Kieras, Polson, and Bovair's in two critical points. First, Singley and Anderson assign weights to the production rules shared by the two tasks, reflecting the frequency of their use. Production rules that are 'higher up' in the goal hierarchy will tend to be used more frequently than the more specialized productions at the lower end of the goal hierarchy and will therefore be assigned larger weights. Consequently, they will figure more prominently in transfer predictions than will productions at the lower end.

Second, Singley and Anderson assume that the components of transfer – production rules – change qualitatively with practice. According to the ACT* theory of learning, all productions arise initially from declarative encodings. With practice, the declarative component, however, will eventually become very small, and transfer will be predictable solely on the basis of procedural knowledge.

Singley and Anderson's theory of transfer makes four important predictions. First, during early stages of learning, transfer is a function of declarative and procedural knowledge. With practice, the impact of the declarative component will rapidly decrease, and transfer will be a function solely of procedural knowledge.

Second, transfer of procedural knowledge is captured by the identical-production-rules theory. That is, the amount of transfer between two tasks depends directly on the number of shared productions in the two tasks.

Third, if the basic components of transfer are productions, then transfer has to be specific to the use of knowledge. This prediction is derived from the condition-action asymmetry of production rules. In particular, the conditions of a rule imply the actions but not vice versa. This property implies the use specificity of knowledge (that is, no transfer) in certain situations where two sets of production rules are based upon the same abstract knowledge but have been dedicated to different uses.

And finally, the theory predicts that negative transfer is minimal. If indeed transfer is determined by the number of shared productions (and that number can never be smaller than zero), then it follows that transfer can be negative only in cases where earlier learned conditions still apply in a new task but now lead to either wrong or nonoptimal actions.

In general, it can be said that the experimental evidence for all four predictions is strong. For instance, Singley and Anderson (1985, 1989) studied transfer among two line editors (ED and EDT) and a screen editor (EMACS). Twenty-four expert typists with no prior text-editing experience were taught a minimum core set of commands for each editor. In the line editors, the core set included commands for printing, deleting, inserting, and replacing lines, and substituting strings within lines. In the screen editor, the core set included commands for moving the cursor forward, backward, and up and down, and deleting characters, words, and strings.

Participants performed the above editing operations for 3 h each day and a total of 6 days. The EMACS group spent all 6 days on EMACS. All other groups spent the last 2 days using EMACS. The ED-EDT and EDT-ED groups spent 2 days on one line editor and the next 2 days on the other. The control group spent 2 days typing at the terminal.

Singley and Anderson split their analyses into two different parts, macroanalyses and microanalyses. Transfer data from the macroanalyses showed near total transfer between the two line editors, moderate transfer from line editors to screen editor, and slight transfer from typing-only to screen editor. The magnitude of predicted transfer (on the basis of relatively simple sets of production systems for the three editors) correlated to .98 with the magnitude of the observed transfer, representing an almost perfect linear relationship between the production overlap predictions and empirical measures of transfer. From these results, Singley and Anderson (1989) concluded that the massive amount of transfer between the two line editors was due to almost identical production systems at both the higher level and the lower level of goal hierarchies, whereas the moderate transfer from line editors to screen editor was primarily mediated by identical higher-order goal structures.

Microanalyses revealed that these general results could vary quite considerably for different subtasks of editing. Singley and Anderson split each unit task into various components of text-editing performance. Their results revealed (1) that a complex task like text editing can be decomposed into different component parts, (2) that each of these components seems to be learned and transferred separately and in accordance with the identical-production-rules theory, and (3) that various components of the task decompose rather cleanly into planning and execution phases, with transfer of planning being much more pronounced than transfer of execution, which can essentially be neglected. In general, this study strongly supported Singley and Anderson's (1989) claim that production rules are the basic components of transfer.

To test the prediction that transfer is confined to the same use of knowledge and does not occur between different uses of the same knowledge, McKendree and Anderson (1987) compared participants' ability in List Processing Language (LISP) evaluation skills. They gave twenty participants four consecutive days of practice in evaluating combinations of four basic LISP functions. Two functions combined items into a list (INSERT and LIST), and the other two extracted items from a list (CAR and CDR – assigned the more mnemonic names of FIRST and REST). Participants practiced 150 trials on each of the 4 days.

After the first and the last session, participants were given a transfer task that required them to generate functions similar to those they had just practiced evaluating. All of the transfer problems involved basic functions or pairs of functions that the participants had seen immediately before in the evaluation task. Yet, while error rates on the evaluation task decreased dramatically from Day 1 to Day 4 (35% to 15%), the transfer task showed little improvement (29.3% to 26.6%). Despite becoming significantly better at evaluating functions, participants on Day 4 were not any better at generating functions than they were on Day 1.

Singley and Anderson's (1985, 1989) theory is easily the best articulated, clearly specified, and most complete theory of transfer to date. By making full use of Anderson's ACT* learning mechanism, the theory is capable of generating interesting and counterintuitive predictions that have already been, and continue to be, subjected to rather thorough and extensive experimental tests.

## 2.31.5 Comparison of Theories of Transfer

### 2.31.5.1 The Content of Transfer

Older S-R-based views of what is learned when a task is acquired and what is transferred from one task to another differ fundamentally from more recent information-processing views. Classical S-R theory and its various descendants all have in common that the most important components of learning are assumed to be associations, whether forward or backward, between externally observable stimuli and responses. In contrast, more recent information-processing theories view learning as the acquisition of general memory structures that are capable of representing observable as well as nonobservable behavior (goals, operators, methods, etc.).

The transition from classical associative theories of transfer to the identical-production-rules view has not been one of degree but has been quite dramatic: Production rules are abstract entities that can be used to describe human behavior at different levels of abstractions. They represent higher-order and lower-order goals as well as externally observable behavior or rule-based reasoning, etc. Using production rules as the basic units of transfer is an entirely different ballgame than relying on associations, stimuli, and responses.

### 2.31.5.2 Effects of First-Task Practice/ Expertise on Transfer

A second important difference between the classical S-R view of transfer and more recent information-processing approaches relates to the effects of expertise on transfer. Classical S-R theory and its various descendants have clearly and unequivocally defended the continuous nature of transfer, characterized by strengthening of associations and increased accessibility of stimuli and responses as a result of increasing expertise. In sharp contrast, the information-processing theories of transfer discussed earlier (with the exception of the static approach taken by Kieras, Polson, and Bovair) have assumed that, because learning is a discontinuous process, transfer is discontinuous also. Thus, the elements of transfer change qualitatively with increasing experience and familiarity on the first task.

However, the assumption that different knowledge representations are transferred to a novel task when the first task has been practiced extensively versus when it has not been practiced extensively has so far not been directly and experimentally demonstrated. In fact, when Singley and Anderson, for instance, modeled text-editing performance in three different text editors, one of their simplifying assumptions was that "the transfer task has the same organization before and after a subject's exposure to the training task" (Singley and Anderson, 1989: 251). This particular aspect shared by all modern theories of transfer, then, clearly is in need of experimental validation.

## 2.31.6 The Doctrine of Formal Discipline Revisited

Virtually all theories of transfer reviewed in this chapter are based upon Thorndike and Woodworth's Theory of Identical Elements (Thorndike and Woodworth, 1901a,b,c); that is, all assume that performance on a second task is (primarily) facilitated by reusing previously acquired specific memory representations. One might conclude then that transfer is primarily specific rather than general. Note, however, that the nature of what specific elements and general methods are has changed so substantially over the past century, as discussed, that it has become virtually impossible to differentiate between general and specific transfer. In fact, by including cognitive constructs as among the common elements that can be transferred, the more recent production system–based approaches have basically eliminated the old distinction between specific and general transfer. The entire task, including aspects of the stimulus and response as well as more general cognitive aspects, can now be described and analyzed under a unified system.

In the last section of the chapter, we briefly discuss some findings that have recently been offered in support of the notion of general transfer. The question we are mainly interested in answering is whether or not these recent findings do indeed lend new credibility to the old Doctrine of Formal Discipline or can alternatively be explained in terms of production system–based transfer theories, as our previous discussion suggests.

One particular recent line of research maintains that practice on a task not only leads to domain-specific task knowledge but to general reasoning skill as well. For example, Lehman et al. (1988; Lehman and Nisbett, 1990) compared the effects of graduate training in psychology, chemistry, medicine, and law on methodological and statistical reasoning. The authors' results revealed positive transfer of medicine and psychology graduate training to the ability to solve reasoning problems in everyday-life situations. In addition, graduate training in law positively affected the ability to solve conditional reasoning problems whereas graduate training in chemistry did not affect any of these abilities.

Thus, the Lehman et al. findings appear to support the assumption of general transfer. In accordance with the Doctrine of Formal Discipline, the authors concluded from their findings that

> . . . rules about assessing causality, rules for generalization, rules for determining argument validity, and rules for assessing the probativeness of evidence . . . (Lehman et al., 1988: 441)

can be taught to improve general thinking skill (see also, Fong et al., 1986; VanderStoep and Shaugnessy, 1997).

More recent experiments (Shraagen, 1993; Schunn and Anderson, 1999) lend further support to the findings of Lehman and colleagues. Schunn and Anderson compared domain experts (cognitive science researchers), task experts (social and developmental psychologists), and domain and task novices (undergraduates) regarding their ability to design memory experiments. Results showed that domain and task experts differed in terms of their domain-specific knowledge and procedures, whereas experts and novices differed in terms of general skills such as the quality of hypothesis generation, data evaluation, developing experimental designs, or drawing conclusions. In addition, the authors ruled out that these general skills were related to IQ. On the basis of the SAT, they divided the novices in their study into those with high abilities and those with low abilities. The performances of the two groups did not differ from each other, but, overall, the two groups were less able to apply general rules than were the two expert groups. The authors concluded that expertise leads to general skills that can be transferred to tasks in unfamiliar domains. The quality of reasoning within a specific domain, however, depends on domain-specific knowledge and processes.

In a subsequent study, Harrison and Schunn (2004) tested scientific reasoning abilities in the domains of psychology and biology of near-experts (graduate students; biologists and psychologists) and novices (undergraduates of both subjects). The authors used a bidirectional transfer paradigm; that is, all participants received problems from biology and psychology. Harrison and Schunn's results again showed that general skills that were applicable in both domains developed with increasing expertise; that is, near-experts were better able to transfer the general skills to unfamiliar domains than were novices.

Again, these findings appear to be consistent with the Doctrine of Formal Discipline. Training in scientific reasoning leads to skill that supports reasoning in other scientific domains or in everyday-life situations. Although the transfer effects were small and transfer was far from complete, the findings suggest that, beyond domain-specific knowledge, experience in one domain also leads to general skill that can facilitate problem solving in other domains. In accordance with findings by Ceci and colleagues (Ceci and Liker, 1986; Ceci and Ruiz, 1992, 1993), this effect of expertise is not related to IQ.

However, it can be shown that the findings described are consistent with and can be explained by production system–based transfer theories. Schunn and Anderson (1999), for instance, argue that participants acquire general search heuristics or production systems when they practice tasks in a domain as well as knowledge (declarative facts in ACT-R) that is used by the search heuristics. Some of the general heuristics that are implemented in production rules can be applied in other than the specific domains in which they have been acquired. This is the case if the new domain provides knowledge that the productions can use. That is, transfer is possible when previously acquired production rules are applicable to knowledge structures in the new domain – in other words, when the new and the old domain share identical features.

Furthermore, the production rule–based transfer theories assume that expertise leads to the strengthening of specific production rules and to the weakening of other rules (e.g., Anderson and Lebière, 1998). This, in turn, might lead to specific preferences in terms of how to approach a given problem. Domain-specific expertise thus shapes how one interprets a given situation and this influence might increase with increasing expertise (e.g., Bransford and Schwartz, 1999; Chen and Klahr, 1999; Harrison and Schunn, 2004; Lehman and Nisbett, 1990). Interestingly, this assumption would predict that expertise in one domain might change how one approaches problems in a new, unfamiliar domain. This effect is what Schwartz et al. (2005) might have had in mind when they proposed to expand the definition of transfer to include 'preparation for future learning.'

The domain-general effect of expertise resembles well-known findings in the field of insight problem solving (e.g., Luchins, 1942; Maier, 1931; Wertheimer, 1959) or of perceptual learning (e.g., Gibson and Gibson, 1955; Goldstone, 1998). For example, in insight problem solving, participants' previously acquired knowledge can prevent their generating the 'correct' mental representation needed to solve the problem at hand (e.g., Knoblich and Oellinger, 2006).

Overall, the recent findings suggest that some general transfer exists. However, rather than supporting the assumption that just about **any** mental activity at Time 1 improves just about **any** subsequent mental activity at Time 2, as was suggested by the Doctrine of Formal Discipline, these findings can be explained in terms of production rule–based transfer theories.

## 2.31.7 Summary and Concluding Remarks

Our main goal in this chapter has been to describe and compare important theories of transfer that have been offered in the psychological literature in the past 100 years. It should be fairly obvious that the nature of transfer theories has changed dramatically from the early days of the Doctrine of Formal Discipline and the Theory of Identical Elements to behaviorist conceptions of transfer and to present-day production system–based conceptions. Currently, the production rule as the unit of transfer provides a quasi-standard way of describing what the identical elements of Thorndike and Woodworth are. As has been argued, the transition from the earlier associationist to a production system–based theory of transfer has not been gradual but has been fairly dramatic. Along with this transition, the earlier distinction between specific and general transfer has lost much of its appeal and meaning. In today's theories, production rules can represent every conceivable piece of information, and whether it refers to observable or unobservable behavior makes little difference.

Being able to specify Woodworth and Thorndike's identical elements is one thing; however, being able to describe and understand the actual process of transfer is a completely different thing. Note that, as the currently dominating theories of transfer, such as Singley and Anderson's, are formulated, they do not capture the actual process of transfer. It is simply not very likely that when they are confronted with a transfer situation, participants create memorial representations of two tasks and then match them against each other. This scenario might help to predict the amount of transfer between two tasks; it does not capture the process of transfer. It seems much more realistic to assume, for instance, that a second task is not represented in isolation in memory when learned, but instead is represented in terms of its deviations from the original task.

In this regard, Polson et al. (1987) describe an interesting process model of transfer in terms of a repair theory. They propose that transfer between overlapping complex skills is largely a repair process where the representation of the first skill is 'edited' in order to reflect the new demands of the transfer task. This repair process is composed of three steps: determining which elements of the old skill need to be repaired, that is, which elements are no longer valid in the transfer task; determining what the new, replacement elements should be; and making the repair.

Polson et al. point out that, in transfer environments that offer both instruction and feedback, the first two steps in the repair process are greatly simplified. However, in situations where the transition between tasks is poorly defined and must be discerned by the participants themselves, interference may be introduced. Indeed, the classic Einstellung phenomenon (Luchins, 1942) can be described as a transfer situation in which the changing demands of the transfer task have not been pointed out explicitly to participants.

Another dramatic demonstration of this effect in a different setting is the classic part-whole negative transfer effect in verbal learning (Tulving, 1966; Sternberg and Bower, 1974). The basic phenomenon is that participants experience negative transfer when learning a second list of words after learning an initial list that is either a subset (part-whole transfer) or superset (whole-part transfer) of the transfer list if they are uninformed about the relation between the first and second word lists. However, if participants are explicitly informed that the transfer list either is a part of or contains the training-list words, the negative transfer turns to strong positive transfer, which is what one would have originally predicted on the basis of an identical elements approach.

Polson et al.'s repair theory has not been extensively tested and can only be regarded as a very rough first approximation of the actual process of transfer. However, it appears to be a rather safe bet to assume that research on the process of transfer will trade places with research on the basic elements of transfer in the very near future and will become one of the most important experimental battlegrounds for theories of transfer.

## References


Anderson JR (1982) Acquisition of cognitive skill. *Psychol. Rev.* 89: 369–406.

Anderson JR (1983) *The Architecture of Cognition*. Cambridge, MA: Harvard University Press.

Anderson JR (1986) Knowledge compilation: The general learning mechanism. In: Michalski RS, Carbonell JG, and Mitchell TM (eds.) *Machine Learning: An Artificial Intelligence Approach,* vol. II, pp. 289–310. Los Altos, CA: Morgan Kaufmann.

Anderson JR (1987) Skill acquisition: Compilation of weak-method problem-solutions. *Psychol. Rev.* 94: 192–210.

Anderson JR and Lebière C (1998) *The Atomic Components of Thought*. Mahwah, NJ: Erlbaum.

Barnett SM and Ceci SJ (2002) When and were do we apply what we learn? A taxonomy of far transfer. *Psychol. Bull.* 128: 612–637.

Bower GH and Springston F (1970) Pauses as recoding points in letter series. *J. Exp. Psychol.* 83: 421–430.

Bower GH and Winzenz D (1969) Group structure, coding, and memory for digit series. *J. Exp. Psychol. Monogr. Suppl.* 80(2): 1–17.

Bransford JD and Schwartz DL (1999) Rethinking transfer: A simple proposal with multiple implications. In: Iran-Nejad A and Pearson PD (eds.) *Review of Research in Education,* vol. 24, pp. 61–100. Washington, DC: American Educational Research Association.

Brown LK, Jenkins JJ, and Lavik J (1966) Response transfer as a function of verbal association strength. *J. Exp. Psychol.* 71: 138–142.

Ceci SJ and Liker JK (1986) A day at the races: A study of IQ, expertise, and cognitive complexity. *J. Exp. Psychol. Gen.* 115: 255–266.

Ceci SJ and Ruiz A (1992) The role of general intelligence in transfer: A case study. In: Hoffman R (ed.) *The Psychology of Expertise*. New York: Springer-Verlag.

Ceci SJ and Ruiz A (1993) The role of context in everyday cognition. In: Rabinowitz M (ed.) *Applied Cognition*, pp. 164–183. Hillsdale, NJ: Erlbaum.

Chen Z and Klahr D (1999) All other things being equal: Acquisition and transfer of the control of variable strategies. *Child Dev.* 70: 1098–1120.

Crowder RG (1976) *Principles of Learning and Memory*. Hillsdale, NJ: Erlbaum.

Dallett KM (1962) The transfer surface re-examined. *J. Verbal Learn. Verbal Behav.* 1: 91–94.

Detterman DK (1993) The case for the prosecution: Transfer as an epiphenomenon. In: Detterman DK and Sternberg RJ (eds.) *Transfer on Trial: Intelligence, Cognition, and Instruction*, pp. 1–24. Norwood, NJ: Ablex Publishing Corporation.

Ebbinghaus HE (1885: 1964) *Memory: A Contribution to Experimental Psychology*. New York: Dover. [Originally published 1885; translated 1913.]

Estes WK (1972) An associative basis for coding and organization in memory. In: Melton AW and Martin E (eds.) *Coding Processes in Human Memory*, pp. 161–190. Washington, DC: Winston.

Ferguson GA (1954) On learning and human ability. *Can. J. Psychol.* 8(2): 95–112.

Fong GT, Krantz DH, and Nisbett RE (1986) The effects of statistical training on thinking about everyday problems. *Cognit. Psychol.* 18: 253–292.

Foss DJ and DeRidder M (1987) Technology transfer: On learning a new computer-based system. In: Carroll JM (ed.) *Interfacing Thought: Cognitive Aspects of Human-Computer Interaction*, pp. 159–183. Cambridge, MA: MIT Press.

Gibson JJ and Gibson EJ (1955) Perceptual learning: Differentiation or enrichment? *Psychol. Rev.* 62: 32–41.

Goldstone RL (1998) Perceptual learning. *Annu. Rev. Psychol.* 49: 585–612.

Goulet LR and Barclay A (1965) A comparison of paired-associate transfer effects between A-B, C-A and A-B, B-C paradigms. *J. Exp. Psychol.* 70: 537–538.

Gray WD and Orasanu JM (1987) Transfer of cognitive skills. In: Cormier SM and Hagman JD (eds.) *Transfer of Learning: Contemporary Research and Applications*, pp. 183–215. New York: Academic Press.

Halpern DF (1998) Teaching critical thinking for transfer across domains. *Am. Psychol.* 53: 449–455.

Harrison AM and Schunn CD (2004) The transfer of logically general scientific reasoning skills. In: Forbus K, Gentner D, and Regier T (eds.) *Proceedings of the 26th Annual Conference of the Cognitive Science Society*, pp. 541–546. Mahwah, NJ: Erlbaum.

Hebb DO (1961) Distinctive features of learning in the higher animal. In: Delafresnaye JF (ed.) *Brain Mechanisms and Learning*, pp. 37–46. New York: Oxford University Press.

Hendrickson G and Schroeder WH (1941) Transfer of training in learning to hit a submerged target. *J. Educ. Psychol.* 32: 205–213.

Hume D (1739/2000) *A Treatise of Human Nature*. Oxford, UK: Oxford University Press.

Hunter WS (1929) Learning: II. Experimental studies of learning. In: Murchison C (ed.) *The Foundations of Experimental Psychology*, pp. 564–627. Worcester, MA: Clark University Press.

Johnson NF (1969) Chunking: Associative chaining versus coding. *J. Verbal Learn. Verbal Behav.* 8: 725–731.

Johnson NF (1970) The role of chunking and organization in the process of recall. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 4, pp. 171–247. New York: Academic Press.

Johnson NF (1972) Organization and the concept of a memory code. In: Melton AW and Martin E (eds.) *Coding Processes in Human Memory*, pp. 125–159. Washington, DC: Winston.

Johnson NF (1978) Coding processes in memory. In: Estes WK (ed.) *Handbook of Learning and Cognitive Processes,* vol. 6, pp. 87–129. Hillsdale, NJ: Erlbaum.

Judd CH (1908) The relation of special training and general intelligence. *Educ. Rev.* 36: 28–42.

Jung J (1962) Transfer of training as a function of degree of first-list learning. *J. Verbal Learn. Verbal Behav.* 1: 197–199.

Karat J (1983) A model of problem solving with incomplete constraint knowledge. *Cognit. Psychol.* 14: 538–559.

Kausler DH (1966) *Readings in Verbal Learning: Contemporary Theory and Research*. New York: John Wiley.

Kausler DH and Kanotti GA (1963) R-S learning and negative transfer effects with a mixed list. *J. Exp. Psychol.* 65: 201–205.

Kieras DE (1982) A model of reader strategy for abstracting main ideas from simple technical prose. *Text* 2: 47–82.

Kieras DE and Bovair S (1984) The role of a mental model in learning to operate a device. *Cogn. Sci.* 8: 255–273.

Kieras DE and Bovair S (1986) The acquisition of procedures from text: A production-system analysis of transfer of training. *J. Mem. Lang.* 25: 507–524.

Kieras DE and Polson PG (1985) An approach to the formal analysis of user complexity. *Int. J. Man Mach. Stud.* 22: 365–394.

Kimball DR and Holyoak KJ (2000) Transfer and expertise. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 109–122. Oxford: Oxford University Press.

Knoblich G and Öllinger M (2006) Einsicht und Umstrukturierung beim Problemlösen [Insight and restructuring in problem solving]. In: Funke J (ed.) *Denken und Problemlösen*, Enzyklopädie der Psychologie, Serie II: Kognition, Vol. 8. Göttingen: Hogrefe.

Lehman DR, Lempert RO, and Nisbett RE (1988) The effects of graduate training on reasoning. *Am. Psychol.* 43: 431–442.

Lehman DR and Nisbett RE (1990) A longitudinal study of the effects of undergraduate training on reasoning. *Dev. Psychol.* 26: 952–960.

Locke J (1693: 1990) *Some Thoughts Concerning Education*. Stuttgart: Reclam.

Luchins AS (1942) Mechanization in problem solving. *Psychol. Monogr.* 54(248).

Maier NRF (1931) Reasoning in humans. II. The solution of a problem and its appearance in consciousness. *J. Comp. Psychol.* 12: 181–194.

Martin E (1965) Transfer of verbal paired associates. *Psychol. Rev.* 72: 327–343.

McGeoch JA (1942) *The Psychology of Human Learning*. New York: Longmans, Green.

McKendree J and Anderson JR (1987) Effect of practice on knowledge and use of Basic Lisp. In: Carroll JM (ed.) *Interfacing Thought: Cognitive Aspects of Human-Computer Interaction*, pp. 236–259. Cambridge, MA: MIT Press.

Melton AW (1963) Implications of short-term memory for a general theory of memory. *J. Verbal Learn. Verbal Behav.* 2: 1–21.

Miller GA (1956) The magical number seven plus or minus two: Some limits on our capacity for processing information. *Psychol. Rev.* 63: 81–97.

Murdock BB Jr. (1958) ''Backward'' associations in transfer and learning. *J. Exp. Psychol.* 55: 111–114.

Newell A and Simon HA (1972) *Human Problem Solving*. Englewood Cliffs, NJ: Prentice-Hall.

Orata PT (1928) *The Theory of Identical Elements, Being a Critique of Thorndike's Theory of Identical Elements and a Re-Interpretation of the Problem of Transfer of Training*. Columbus: Ohio State University Press.

Osgood CE (1949) The similarity paradox in human learning: A resolution. *Psychol. Rev.* 56: 132–143.

Perkins DN and Salomon G (1992) Transfer of learning. In: Husen T and Postlethwaite TN (eds.) *International Encyclopedia of Education,* 2nd edn., pp. 2–13. Oxford: Pergamon Press.

Polson PG (1987) A quantitative theory of human-computer interaction. In: Carroll JM (ed.) *Interfacing Thought: Cognitive Aspects of Human-Computer Interaction*, pp. 184–235. Cambridge, MA: MIT Press.

Polson PG and Kieras DE (1984) A formal description of users' knowledge of how to operate a device and user complexity. *Behav. Res. Methods Instrum. Comput.* 16: 249–255.

Polson PG and Kieras DE (1985) A quantitative model of the learning and performance of text editing knowledge. In: Borman L and Curtis B (eds.) *Proceedings of the ACM CHI 85 Human Factors in Computing Systems Conference*, pp. 207–212. San Francisco, 14–18 April. New York: Association for Computing Machinery.

Polson PG, Bovair S, and Kieras DE (1987) Transfer between text editors. In: Carroll JM and Tanner P (eds.) *Human Factors in Computing Systems and Graphics Interface: CHI + GI 1987 Conference Proceedings*, pp. 89–91. New York: Association for Computing Machinery.

Polson PG, Muncher E, and Kieras DE (1987) *Transfer of Skills between Inconsistent Editors.* Technical Report # 87–10. Boulder: University of Colorado.

Schulz RW and Martin E (1964) Aural paired-associate learning: Stimulus familiarization, response familiarization, and pronouncability. *J. Verbal Learn. Verbal Behav.* 3: 139–145.

Schunn CD and Anderson JR (1999) The generality/specificity of expertise in scientific reasoning. *Cogn. Sci.* 23: 337–370.

Schwartz DL, Bransford JD, and Sears D (2005) Efficiency and innovation in transfer. In: Mestre J (ed.) *Transfer of Learning from a Modern Multidisciplinary Perspective*, pp. 1–51. Greenwich, CT: Information Age Publishing.

Shraagen JM (1993) How experts solve a novel problem in experimental design. *Cogn. Sci.* 17: 285–309.

Singley MK and Anderson JR (1985) The transfer of text-editing skill. *Int. J. Man Mach. Stud.* 22: 403–423.

Singley MK and Anderson JR (1989) *The Transfer of Cognitive Skill*. Cambridge, MA: Harvard University Press.

Slamecka NJ (1964) An inquiry into the doctrine of remote associations. *Psychol. Rev.* 71: 61–76.

Sternberg RJ and Bower GH (1974) Transfer in part-whole and whole-part free recall: A comparative evaluation of theories. *J. Verbal Learn. Verbal Behav.* 13: 1–26.

Thorndike EL and Woodworth RS (1901a) The influence of improvement in one mental function upon the efficiency of other functions. *Psychol. Rev.* 8: 247–261.

Thorndike EL and Woodworth RS (1901b) The influence of improvement in one mental function upon the efficiency of other functions. (II.) The estimation of magnitudes. *Psychol. Rev.* 8: 384–395.

Thorndike EL and Woodworth RS (1901c) The influence of improvement in one mental function upon the efficiency of other functions. (III.) Functions involving attention, observation, and discrimination. *Psychol. Rev.* 8: 553–564.

Trabasso T and Bower GH (1968) *Attention in Learning*. New York: John Wiley and Sons.

Tulving E (1966) Subjective organization and effects of repetition in multi-trial free-recall learning. *J. Verbal Learn. Verbal Behav.* 5: 193–197.

Twedt HM and Underwood BJ (1959) Mixed vs. unmixed lists in transfer studies. *J. Exp. Psychol.* 58: 111–116.

VanderStoep SW and Shaughnessy JJ (1997) Taking a course in research methods improves reasoning about real-life events. *Teach. Psychol.* 24: 122–124.

Wertheimer M (1959) *Productive Thinking*. New York: Harper.

Wimer C (1963) An analysis of semantic stimulus factors in paired-associate learning. *J. Verbal Learn. Verbal Behav.* 1: 397–407.

# 2.32 Implicit Learning

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## 2.32.1 Introduction

All of us have learned much without parental supervision and outside of any form of planned academic instruction, and more generally without any intentional attempts to acquire information about the surrounding world. Countless examples could be found in domains as diverse as first-language acquisition, category elaboration, sensitivity to musical structure, acquisition of knowledge about the physical world, and various social skills. All of these domains have several features in common. In particular, they are commonly described as governed by complex abstract rules by scientists, whether they would be linguists, musicologists, physicists, or sociologists. Also, learning in those situations mainly proceeds through the learner's exposure to a structured environment, without negative evidence (i.e., without direct information about what would contradict the rules underlying the domain).

Despite the pervasiveness of these forms of learning in real-world settings, it is worth stressing that they have been virtually ignored by experimental psychology for decades. At the beginning of the cognitive era, the study of learning was essentially devoted to classical and operant conditioning on the one hand, and to the formation of concepts or problem solving processes on the other. The above phenomena seem hardly reducible to simple conditioning effects in regards to their complexity, and research on concept learning and problem solving does not provide *a priori* a better account, primarily due to the fact that the hypothesis testing strategies essential in these research domains do not seem applicable in situations where negative evidence is lacking. This empirical and conceptual vacuum opened the door to the upsurge of the nativist perspective, which characterized the cognitive approach from its outset.

This chapter presents a stream of research that is primarily aimed at exploring the forms of learning illustrated in the examples above through laboratory situations involving arbitrary materials (for overviews, see Berry and Dienes, 1993; Berry, 1997; Cleeremans et al., 1998; French and Cleeremans, 2002; Jimenez, 2003; Perruchet and Pacton, 2006; Reber, 1993; Seger, 1994; Shanks, 2005; Stadler and Frensch, 1998). This field of research evolved essentially from the end of the 1980s, although its roots are in the pioneering studies of Arthur Reber, who coined the term 'implicit learning' (IL) about 40 years ago (Reber, 1967). The implications of the results issued from IL research for the nativist/empiricist debate will be addressed in the final discussion, after having examined what is learned in this context, how 'implicit' is implicit learning, and the relations of laboratory research with real-world situations of learning.

## 2.32.2 Rules, Instance-Based Processing, or Sensitivity to Statistical Regularities?

### 2.32.2.1 Learning Rules

A large part of the literature on IL exploits the artificial grammar learning paradigm, initially proposed by Reber (1967). Participants first study a set of letter strings generated from a finite-state grammar that defines legal letters and permissible transitions between them (**Figure 1**). Typical instructions do not mention the existence of a grammar and are framed so as to discourage participants from engaging in explicit, intentional analysis of the material. Participants are then subsequently informed about the rule-governed nature of the strings and asked to categorize new grammatical and nongrammatical letter strings. Participants are typically able to perform this task with better-than-chance accuracy, while remaining unable to articulate the rules used to generate the material. This empirical outcome has been unambiguously confirmed by a vast number of subsequent experimental studies involving many variants of the situation.

Reber's (1967) original proposal was that participants have internalized the constraints embodied by

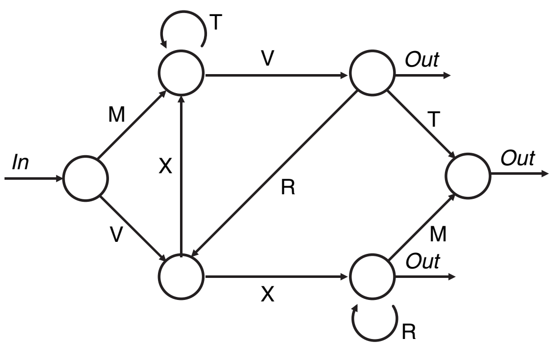


**Figure 1** The artificial grammar used by Reber and Allen (1978), Dulany et al. (1984), and Perruchet and Pacteau (1990) among others. For example, MTTV and VXVRXVT are grammatical, whereas MXVT is not grammatical.

the generation of rules during training. Rule abstraction is assumed to occur during the study phase, when participants are exposed to a sample of letter strings generated from the grammar. During the test phase, participants are assumed to use the acquired knowledge, stored in an abstract format, to judge the grammaticality of new items. Other illustrations of this reasoning can be found in many subsequent studies. Let us consider those by Lewicki et al. (1988) and McGeorge and Burton (1990).

In the Lewicki et al. (1988) paradigm, participants were asked to perform a four-choice reaction-time task, with the targets appearing in one of four quadrants on a computer screen. They were simply asked to track the targets on the numeric keypad of the computer as fast as possible. The sequence looked like a long and continuous series of randomly located targets. However, this sequence was organized on the basis of subtle, nonsalient rules. Indeed, unbeknown to participants, the sequence was divided into a succession of 'logical' blocks of five trials each. In each block, the first two target locations were random, while the last three were determined by rules. The participants were unable to verbalize the nature of the manipulation and, in particular, they had no explicit knowledge of the subdivision into logical blocks of five trials, which was a precondition that had to be satisfied if they were to grasp the other rules. However, performance on the final trials of each block, the locations of which were predictable from the rules, improved at a faster rate and was better overall than performance on the first, random, trials. Lewicki et al. (1988) accounted for these results by postulating that the structuring rules were discovered by a powerful, multipurpose unconscious algorithm abstractor.

In the McGeorge and Burton (1990) study, which initiated a stream of research on the so-called 'invariant learning,' participants were asked to perform an arithmetic task on a set of four-digit numbers. Unbeknown to them, each four-digit number contained one '3' digit (the 'invariant'). In a subsequent forced-choice recognition test, participants were shown 10 pairs of four-digit numbers. They were told that one of the numbers in each pair was seen during the study phase, and that they had to find it. In fact, all the numbers were new, but half of them contained one '3' as in the study strings, while no '3' occurred in the other half. Participants choose above chance the numbers containing a '3,' although they were unable to report anything pertinent to the invariant digit. The authors inferred that participants had learned the critical rule unconsciously.

These results, and most of the others in the early IL literature, have been shown to be empirically robust in subsequent studies. However, two other interpretations have been proposed. Their common intuition is that people do not abstract the rules of the domain, but instead learn about the product of the rules.

### 2.32.2.2 The Instance-Based or Episodic Account

The first historical alternative to the abstractionist position in the field of artificial grammar learning is the so-called instance-based or memory-based model proposed by Brooks (Brooks, 1978; Vokey and Brooks, 1992). In Brooks' model, subjects who are shown grammatical strings during the study phase store the strings in memory, without any form of condensation or summary representation. During the test phase, they judge for grammaticality of test strings as a function of their similarity to specific stored strings. The instance-based model works because, if no special care is taken to generate the material, grammatical test items tend to look globally more similar to study items than ungrammatical test items.

Vokey and Brooks (1992) made independent the usually confounded factors of specific similarity and grammaticality, in order to assess the size of the effect of each factor on grammaticality judgments. Test items were classified as similar when they differed by only one letter from one study item, and dissimilar when they differed by two or more letters from any study items. The authors obtained a reliable effect of specific similarity on grammaticality judgments (see also McAndrews and Moscovitch, 1985). As expected, similar items were more often classified as grammatical than dissimilar items when their grammatical status (i.e., their consistency with the grammar) was kept constant. However, the grammaticality factor also had a significant, and usually additive, effect. Similar evidence was collected by Cock et al. (1994) in invariant learning. The authors demonstrated that similarity to instances in the study phase was even a more important factor than apparent knowledge of the invariant feature in the McGeorge and Burton (1990) paradigm.

To account for the fact that the similarity to a specific training item fails to account for all the variance in performance, Vokey and Brooks (1992; Brooks and Vokey, 1991) suggested that the similarity may also be computed with the whole set of study items instead of a single one (see also Pothos and Bailey, 2000, for another measure of similarity). The currently prevalent interpretation keeps the idea of some kind of pooling or summation over multiple episodes, but privileges a formulation in terms of statistical regularities.

### 2.32.2.3 The Sensitivity to Statistical Regularities

While the instance-based model considers whole episodes (e.g., VXVRXVT in artificial grammar learning), this alternative account considers elementary components (e.g., the individual letters). The consequences are considerable. Indeed, large episodes are idiosyncratic, and hence they generate distinctive and independent memory traces. By contrast, elementary components occur iteratively under the same or other combinations, and hence it makes sense to describe the to-be-learned stimuli using statistical concepts, such as frequency, probability, or contingency. For this reason, this approach is designated here as the statistical account, even though it is most commonly referred to as the 'fragmentary' approach in the conventional IL literature. It is worth noting that the term 'statistics' does not necessary entail that learners perform statistical computations, an issue that will be addressed later (see the section titled 'Statistical computations and chunk formation').

The general principle of this account is straightforward: Organizing rules generates statistical regularities in the world, and people adjust their behavior to those regularities. Understanding how this account works in artificial grammar learning is easy. Looking at the grammar shown in **Figure 1**, it appears that that some associations between letters are possible (e.g., MV), and other impossible (e.g., MX), and that among the legal associations, some are more frequent than others (e.g., RX presumably occurs more often than RM). If participants learn something about the frequency distribution of the pairs of letters (bigrams) that compose the study strings, they should perform subsequent grammaticality judgments better than chance. Perruchet and Pacteau (1990) tested this hypothesis. They reasoned that, if subjects learn only bigram information when faced with the whole strings, the direct presentation of the bigrams, which precludes the use of any high-level rules, should not change the final performance. The prediction was confirmed; the performance of participants who had learned using the complete grammatical strings (as usual) and those who were trained using the bigrams from which these strings were composed were statistically indistinguishable. Other experiments from the same study and other studies (Dienes et al., 1991; Gomez and Schvaneveldt, 1994) confirmed the importance of bigrams knowledge, although they showed that participants also learn other piecemeal information, such as the location of permissible bigrams and the first and last letters of the strings.

The question is now: Does this interpretation work in general? It could be argued indeed that artificial grammar learning is especially well-fitted to a statistical interpretation, because the rules can be easily translated in terms of statistical regularities. To address this question, let us consider how the Lewicki et al. (1988) study presented above can be reinterpreted. Recall that a precondition to grasp the complex second-order dependency rules structuring the sequence was a parsing of the whole sequence into logical blocks of five trials, and that participants were fully unconscious of doing so. However, Perruchet et al. (1990) demonstrated that participants could learn the task without ever performing the segmentation of the sequence into logical blocks. Instead, they could become sensitive to the relative frequency of small units, comprising two or three successive locations. Some of the possible sequences of two or three locations were more frequent than others, because the rules determining the last three trials within each five-trial block prohibited certain transitions from occurring. In particular, an examination of the rules shows that they never generated back-and-forth movements. As a consequence, the back-and-forth transitions were less frequent *on the whole sequence* than the other possible movements. The crucial point is that these less frequent events, which presumably elicit longer reaction times, were exclusively located on the random trials. This stems not from an unfortunate bias in randomization, but from a logical principle: The rules determined both the relative frequency of certain events within the entire sequence and the selective occurrence of these events in specific trials (for an alternative interpretation based on connectionist modeling, see Cleeremans and Jimenez, 1998).

A similar reanalysis was performed by Wright and Burton (1995) on the McGeorge and Burton (1990) invariant task. Wright and Burton observed that a by-product of the invariant rule was to modify the probability of occurrence of observing a digit repetition in the strings. More precisely, the strings that contain one ‘3’ include, on the mean, a smaller proportion of repeated digits than the strings in which no ‘3’ occurs, all simply because the chances of generating repeated digits are lesser over three than over four successive drawings. The authors showed that at least a part of the participants’ above-chance performance during the test was due to the fact that they tended to reject the items containing repetitions, rather than the items violating the invariant rule.

What is new in these examples (for a similar illustration, see the reinterpretation of Kushner et al. (1991) by Perruchet (1994b)) with regard to the artificial grammar-learning situation is the fact that the link between the generating rules and the distributional statistics of simple and salient events is far from obvious. The fact that rules may have remote consequences, the learning of which having effects similar to the learning of the rules themselves, may obviously be thought of as a drawback in the experimental designs, without any implication out of the laboratory studies. However, it may also be thought of as a quite fundamental outcome, essential to understand the power of the statistical approach in the natural situation of learning, as the section titled ‘Discussion: about nativism and empiricism’ will emphasize.

### 2.32.2.4 Rules versus Statistics: A Crucial Test

How can rule-based and statistical interpretations be discriminated? When the rules of a domain generate a set of events so restricted that all the possible events can be exhaustively experienced by a subject, it may be impossible to discriminate between the two types of interpretations. However, this case is largely deprived of interest. Indeed, the power of the rules is that they make people able to adapt to new situations from previous exposure to a subset of the events the rules can generate. Here is the hint for a crucial test.

For a first example, let us consider an argument for rules put forth by Reber and Lewis (1977) in the context of artificial grammar learning. In a given experiment, participants are exposed to a subset of the virtual full set of strings generated by the grammar, and this subset cannot be perfectly representative of the full set for all aspects. For instance, the frequency distribution of the observed bigrams has a high probability of departing to some extent from the frequency of the bigrams composing the full set of strings. Reber and Lewis argued that if participants abstract the rules of the grammar, they should be sensitive to the bigram frequency of the virtual full set of strings, and not the frequency of occurrence of the bigrams composing the strings actually displayed in the study phase. They provided empirical data supporting this hypothesis, and Reber (1989) construed these data as one of the main supports for his contention that studying grammatical letter strings gives access to the abstract structure of the grammar. The logic of the argument is indeed sound, but unfortunately, the supporting data turned out to be due to various methodological drawbacks inherent to the Reber and Lewis procedure (Perruchet et al., 1992). In fact, participants are sensitive to the frequency distribution of the bigrams they actually perceived.

In the preceding example, the possibility of discriminating interpretations based on rules and statistics stems from the fact that the subset of items to which participants are exposed are not representative of the whole set of items due to sampling biases. The same logic may be implemented in a more systematic way, by training participants with a given material and testing them with different material. The following section examines the findings obtained in these so-called ‘transfer’ situations, which have been heavily used in IL research.

### 2.32.2.5 The Phenomenon of Transfer: The Data

In the standard paradigm of transfer in artificial grammar learning, the letters forming the study items are changed in a consistent way for the test of grammaticality (e.g., M is always replaced by C, X by P, etc.). Reber (1969) and several subsequent studies (e.g., Mathews et al., 1989; Dienes and Altmann, 1997; Manza and Reber, 1997; Shanks et al., 1997; Whittlesea and Wright, 1997) have shown that participants still outperform chance level under these conditions. The principle underlying the ‘changed letter procedure’ has been extended to other surface changes. For instance, the training items and the test items may be, respectively, auditory items and visual items (Manza and Reber, 1997), color and color names, sounds and letters (Dienes and Altmann, 1997), or vice versa. Successful transfer was observed in each case.

The phenomenon of transfer has also been observed in invariant learning. McGeorge and Burton (1990) found that the selection of number strings containing the invariant digit persisted when study strings were presented as digits (e.g., 1234) and test strings as their word equivalents (e.g., one two three four; see Bright and Burton (1998) for similar examples of transfer in another invariant learning task).

Transfer has even been observed in infants. In Marcus et al. (1999), 7-month-old infants were exposed to a simplified, artificial language during a training phase. Then they were presented with a few test items, which were all composed of new syllables. For instance, in one experiment, infants heard 16 three-word sentences such as *gatiti, linana,* or *tanana,* during the study phase. All of these sentences were constructed on the basis of an ABB grammar. The infants were then presented with 12 other three-word sentences, such as *wofefe* and *wofewo.* The crucial point is that, although all of the test items were composed of new syllables, only half of the items were constructed from the grammar with which the infants had been familiarized. In the selected example, the grammatical item was *wofefe. Wofewo* introduces a structural novelty in that it is generated from a concurrent ABA grammar. The infants tended to listen more to the sentences generated by the ABA grammar, thus indicating their sensitivity to the structural novelty. In another experiment, infants were shown to be able to discriminate sentences generated by an AAB grammar. Similar studies using more complex material have been performed with 11-month-old infants (Gomez and Gerken, 1999).

## 2.32.2.6 The Phenomenon of Transfer: The Interpretations

### *2.32.2.6.1 Rules?*

Marcus et al. concluded that infants have the capacity to represent algebraic-like rules and, in addition, "have the ability to extract those rules rapidly from small amounts of input and to generalize those rules to novel instances" (Marcus et al., 1999, p. 79). Demonstrations of transfer in more complex situations in adults have elicited similar comments. For instance, Reber, talking about performance in the changed letter procedure in artificial grammar learning studies, claimed that

> . . . the abstractive perspective is the only model of mental representation that can deal with the existence of transfer of knowledge across stimulus domains. (Reber, 1993: 121)

A rule-based interpretation may have difficulty accounting for the entire pattern of data, however. First, the traditional emphasis on positive results must not overshadow the fact that transfer failure has frequently been reported in the literature on IL. In the conclusion of their review on transfer in the most current IL paradigms, Berry and Dienes pointed out that

> . . . the knowledge underlying performance on numerous tasks . . . often fails to transfer to different tasks involving conceptually irrelevant perceptual changes. (Berry and Dienes, 1993: 180)

This empirical finding leads the authors to propose that limited transfer to related tasks is one of the important key features of performance in IL tasks. Moreover, in experiments where positive evidence of transfer is reported, performance levels on transfer situations are generally lower than performance levels on the original training situation. This so-called transfer decrement phenomenon raises a problem for a rule-based standpoint. In an authoritative discussion on the use of abstract rules, Smith et al. (1992) posit as the first of their eight criteria for rule use that "Performance on rule-governed items is as accurate with unfamiliar as with familiar material" (Smith et al., 1992, p. 7; see also Anderson, 1994, p. 35; Shanks, 1995, Ch. 5; Whittlesea and Dorken, 1997, p.66). Manza and Reber (1997) acknowledge this implication of their own abstractionist view. Clearly, this prediction of rule-based accounts has scarce experimental support at best.

However, observing that rule-based interpretation of transfer is, after all, not so well-fitted as might expected has limited interest until better interpretations are put forward. Are there alternatives?

### *2.32.2.6.2 Explicit inferences during the test?*

In the standard situations of artificial grammar learning, most people are able to learn the abstract rules of the grammar when they are instructed to search for rules (Turner and Fischler, 1993) or when they are given incidental instructions which guide them toward the deep structure of the material (Wittlesea and Dorken, 1993). A first alternative possibility to account for transfer in IL studies is that transfer is due to the involvement of explicit reasoning, despite the instructions given to participants.

This account finds support in the examination of the tasks in which transfer routinely succeeds and tasks in which transfer fails. As noted by Newell and Bright (2002), the tasks that trigger transfer are those in which participants are instructed to use knowledge that they have acquired during training, such as artificial grammar learning tasks and invariant learning tasks. These instructions inevitably shift subjects to a rule-discovery mental set. The tasks in which subjects are not explicitly engaged to rely on what they saw in study phase, such as serial reaction-time (SRT) tasks and control interactive tasks, are far less prone to transfer. In SRT tasks, for instance, a target stimulus appears on successive trials at one of a few possible positions on the computer screen. Participants are simply asked to react to the appearance of the target by pressing a key that spatially matches the location of the target on a keyboard. Typically, the same sequence of trials is repeated throughout the session. Participants exhibit a decrease in reaction times with regard to a control condition, without ever being informed about the presence of a repeated structure. In this case, transfer to dissimilar surface feature typically fails (Stadler, 1989; Willingham et al., 1989).

The role of explicit reasoning in changed-letter transfer in artificial grammar learning is further suggested by the fact that transfer is performed better when the training session involves intentional (i.e., rule searching) rather than incidental instructions (Mathews et al., 1989). Whittlesea and Dorken (1993) failed to obtain changed-letter transfer in subjects whose attention was not focused on the structure of the situation. In the same vein, Gomez (1997) showed that changed-letter transfer occurred only in subjects who had sufficient explicit knowledge of the rules.

Although these studies suggest that transfer performance partly depends on the involvement of conscious and deliberate processes, it is difficult to account for all the positive results in those terms. To evoke only one counterargument, the observation of transfer in infants (Gomez and Gerken, 1999; Markus et al., 1999) can hardly be explained by the recourse to intentional rule-breaking strategies. Is it possible to account for transfer in IL without any recourse to rules?

#### *2.32.2.6.3 Disentangling rules and abstraction*

There is no doubt that the evidence of transfer is indicative of abstraction. However, the view that abstraction is indicative of rule formation and rule use has been heavily challenged. As cogently argued by Redington and Chater (2002), "surface-independence and rule-based knowledge are orthogonal concepts."

To begin with a simple case, let us consider Manza and Reber's (1997) results, showing a transfer between auditory and visual modalities in the artificial grammar learning area. These authors interpret their findings as providing support for their abstractionist, rule-based view. However, the phenomenon can be easily explained otherwise. Any sequence – such as VXMTR – presented orally will be immediately recognized when displayed visually, irrespective of whether this sequence is generated by a grammar or not. This is because the perceptual primitives, namely the letters V, X, and so on, are processed to an abstract level that makes them partially independent of their sensory format. The differences between the two explanations is worth stressing. In the former case, a rule-governed pattern is assumed to be extracted from the auditory stimuli before being applied to the visual stimuli. In the latter case, matching is directly performed at the levels of the perceptual primitives. The same comment can be applied to many other studies. For example, the transfer between colors and the name of colors (Dienes and Altmann, 1997) and the transfer between digits and their word equivalents (McGeorge and Burton, 1990) can also be accounted for by the natural mapping between the primitives involved in the experiment.

At first glance, the above explanation does not apply to all transfer results. As a case in point, it does not seem to work for the studies by Marcus et al. (1999) in which transfer is observed between, say, *gatiti* and *wofefe*, because there is no natural mapping between *ga* and *wo*, or *ti* and *fe*. Reinterpretation of the Marcus et al. data is possible along the same line, however, if one assumes that the perceptual primitives can be relational in nature. The relation that needs to be coded is the relation 'same-different,' or, in other words, the only ability that infants need to possess is that of coding the repetition of an event. Indeed, as pointed out by McClelland and Plaut (1999), *gatiti, wofefe*, and more generally all the ABB items, can be coded as different-same, whereas none of the other items can be coded using the same schema.

As surprising as this conclusion may be, the demonstrations of transfer stemming from the more complex situations of artificial grammar learning in adults imply the coding of no more complex relations than event repetitions (e.g., Tunney and Altmann, 1999; Gomez et al., 2000; for an overview, see Perruchet and Vinter, 2002, Section 6). Lotz and Kinder (2006) confirmed and extended this conclusion. They showed that the sources of information used in transfer tasks in artificial grammar learning studies concern the local repetition between adjacent elements, as well as the repetition of nonadjacent elements in the whole items.

Overall, this analysis demonstrates that transfer, such as observed in IL settings, is in no way indicative of rule knowledge. It is fairly compatible with a statistical approach, provided one acknowledges the possibility that statistical processes operate not only on surface features (such as forms or colors), but also on more abstract properties and on simple relational features, such as the repetition of events. The idea that transfer does not imply rule abstraction has also gained support from the possibility of accounting for transfer performance within a connectionist framework (Altman and Dienes, 1999; McClelland and Plaut, 1999; Seidenberg and Elman, 1999; Christiansen and Curtin, 1999). Note also that transfer has been claimed to be compatible with an interpretation focusing on instance-based processing, thanks to the notion of abstract analogy (Brooks and Vokey, 1991), although Lotz and Kinder (2006) failed to find an empirical support for this account.

### 2.32.2.7 A Provisional Conclusion

There is evidence that the analogy with specific items may account for a specific part of variance in performance. The Vokey and Brooks (1992) demonstration, presented in the section titled 'The instance-based or episodic account,' has been challenged (Knowlton and Squire, 1994; Perruchet, 1994a), but additional evidence has been provided since then (Higham, 1997). The interest of the instance-based model resides in its highlighting the fact that behavior may be implicitly affected by individual episodes rather than simply by large amounts of training. However, there is a consensus on the idea that this account cannot be thought of as exclusive. It seems inevitable to jointly consider the pooled influence of a series of events to account for the whole pattern of data.

The two main views accounting for the influence of multiple past events are based on rules and statistics, respectively, but there is no symmetry between the two accounts. Indeed, no one disputes the existence of statistical learning. This consensus comes from the human ability to learn in the countless situations in which regularities cannot be described by a set of rules, as the concept has been defined above. As a consequence, the only possible question is: Do we need rules, in addition to statistical learning, to account for implicit learning in rule-governed situations?

Here is the end of the consensus. On the one hand, many authors respond "no." Their position is based on the fact that the sensitivity to statistical regularities is able to account for performance in most of the experimental situations that were initially devised to provide an existence proof for rule learning, including transfer settings. In addition, when a direct test has been performed to contrast the predictions of the two models, predictions of the statistical account have been unambiguously confirmed (see also Perruchet (1994b) on the situation devised by Kushner et al. (1991) and Channon et al. (2002) on the biconditional grammar). On the other hand, other authors (e.g., Knowlton and Squire, 1996) argue that empirical evidence requires a dual process account, mixing statistical learning and rule knowledge. Their position stems from experimental studies in which learning persists in test conditions where the simplest regularities – those that are presumably captured by statistical learning – have been made uninformative (e.g., Knowlton and Squire, 1996; Meulemans and Van Der Linden, 1997; but see Kinder and Assmann, 2000). This kind of evidence is not fully compelling, however, because it is not possible to ascertain that all the possible sources of statistical knowledge have been taken into account (see for instance the reanalysis of Meulemans and Van der Linden (1997) by Johnstone and Shanks (1999)). A more principled demonstration, in which some specified content of knowledge would fail to be approximated by statistical learning, would provide a far stronger argument.

The remaining of this chapter focuses on statistical learning. This does not mean that the possibility of implicit rule learning can be considered as definitely ruled out. This presumably will never be the case, because proof of nonexistence is beyond the scope of any empirical investigation. Needless to say, this approach does not mean either that rule learning does not exit at all; there is clear evidence that humans are able to infer and use abstract rules when conscious thought is involved. The very existence of science should provide a sufficient proof for the skeptic.

The implications of focusing on statistical learning are that the questions and their experimental approach will be considered irrespectively of whether the to-be-learned materials can be described in terms of rules or not. Note that this focus is in keeping with the recent literature on IL, which typically includes a number of situations that are not governed by rules such as SRT tasks with repeated sequences and word segmentation (e.g., Saffran et al., 1997), as well as other situations, such as contextual cuing (Chun and Jiang, 2003), that are not described in this chapter due to space limitations.

## 2.32.3 Learning about Statistical Regularities

Before examining the question of what processes underlie behavioral tuning to statistical regularities, one needs to identify the kinds of regularities to which humans are sensitive.

### 2.32.3.1 What Is Learnable?

#### *2.32.3.1.1 Frequency, transitional probability, contingency*

For many people, claiming that behavior is sensitive to statistical regularities amounts to saying that behavior is sensitive to the absolute or the relative frequency of events. For instance, participants in an artificial grammar experiment may have learned that MT occurred $n$ times, or that a proportion $p$ of the displayed bigrams were MT. Considering only frequency provides limited information, however. It may be interesting to know the probability for 'M' to be followed by 'T,' a measure called conditional or transitional probability. To assess whether 'M' is actually predictive of 'T,' this probability must be compared to the probability that another letter precedes 'T'. The difference between these two conditional probabilities is called DeltaP (Shanks, 1995). In addition, it may be worth considering the reverse relations, namely the probability for 'T' to be preceded by 'M.' This 'backward' transitional probability may be quite different from the standard, forward transitional probability. The normative definition of contingency in statistics (such as measured, for instance, by a $\chi^2$ or a Pearson correlation) requires a consideration of the bidirectional relations. When data are dichotomized, for instance, Pearson correlation is the geometrical mean of the forward and backward DeltaP (for a more detailed presentation, see Perruchet and Peereman, 2004).

The focus on frequency in early studies on IL does not mean that human behavior is only sensitive to this variable. Indeed, all the measures of association are generally correlated, so evidence collected to support one specific measure is equivocal if no special care is taken for controlling the other measures. Aslin et al. (1998) demonstrated that participants were sensitive to the transitional probability in word-segmentation studies. These results have been replicated in visual tasks (e.g., Fiser and Aslin, 2001), so that most recent studies on statistical learning take for granted that the statistics to which people are sensitive are transitional probabilities. This conclusion could be premature, given the correlations between the different measures, and the paucity of studies including different measures. In fact, the literature on conditioning has long suggested that even animals such as rats or pigeons are sensitive to DeltaP (Rescorla, 1967). Perruchet and Peereman (2004) compared several measures of associations, and they found that participants were more sensitive to the bidirectional contingency than to simpler measures of associations (although in a specific context). A conservative conclusion could be that people are sensitive to more sophisticated measures of associations than co-occurrence frequency, and further study is needed for assessing more precisely which statistic is the more relevant in each context.

#### *2.32.3.1.2 Adjacent and nonadjacent dependencies*

A dimension orthogonal to the previous one concerns the distance between the to-be-related events. The early studies endorsing a statistical approach in the IL domain focused on adjacent elements (typically the bigrams of letters). The importance of adjacent relations, however, does not mean that it is impossible to learn more complex information. A number of studies in SRT tasks have investigated how reactions times to the event $n$ improved due to the information brought out by the events $n$-1, $n$-2, $n$-3 (known as first-order, second-order, and third-order dependency rules, respectively), and so on. Second-order dependencies can be learned quite easily and are now used as a default in most SRT studies. Third-order dependency rules can also be learned, although less clearly (Remillard and Clark, 2001). However, higher-order dependency rules are seemingly much harder, or impossible to learn. For instance, even after 60 000 practice trials, Cleeremans and McClelland (1991) obtained no evidence for an effect of the event four steps away from the current trial.

In the situations discussed so far, the relations between distant events are not considered independently from the intervening events. By contrast, in the AXC structures investigated in several recent studies, a relation exists between A and C irrespective of the intervening event X, which is statistically independent from both A and C. Examining whether learning those nonadjacent relationships is possible was prompted by the fact that these relations are frequent in high-level domains such as language and music. The studies investigating the possibility of learning nonadjacent dependencies between syllables or words (Gomez, 2002; Newport and Aslin, 2004; Perruchet et al., 2004; Onnis et al., 2005), musical sounds (Creel et al., 2004; Kuhn and Dienes, 2005), digits (Pacton and Perruchet, in press), and visual shapes (Turk-Browne et al., 2005) report positive results. However, most of them conclude that learning nonadjacent dependencies presupposes more restrictive conditions than those required for learning the relations between contiguous events. Gomez (2002) showed that the degree to which the A_C relationships were learned depended on the variability of the middle element (X). For Newport, Aslin, and collaborators (e.g. Newport and Aslin, 2004), the crucial factor is the similarity between A and C. Learning seems also much easier in a situation where the successive AXC units are perceptually distinct (e.g., Gomez, 2002), than in situations where they are embedded in a continuous sequence (e.g., Perruchet et al., 2004). By contrast, Pacton and Perruchet (in press) provided support for a view in which nonadjacent dependencies can be learned as well as adjacent dependencies insofar as the relevant events are actively processed by participants to meet the task demands.

#### 2.32.3.1.3 Processing multiple cues concurrently

Up to now, we have examined how the learner exploits one source of information, for instance, event repetition. However, taken in isolation, a source of information often has a limited value in real-world settings. The system efficiency would be considerably extended if various sources could be exploited in parallel. The number of studies exploring this issue is still tiny, but they provide converging evidence for a positive assessment, as well in artificial grammar learning (e.g., Kinder and Assmann, 2000; Conway and Christiansen, 2006) as in SRT tasks (e.g., Hunt and Aslin, 2001). Studies on word segmentation have also demonstrated the possibility of combining statistical and prosodic cues (e.g., Thiessen and Saffran, 2003). The concurrent exploitation of various information sources can be simulated by connectionist networks (e.g., Christiansen et al., 1998), a feature that strengthens the plausibility of such a possibility in humans.

#### 2.32.3.1.4 Does learning depend on materials?

An impressive amount of data suggests that statistical learning mechanisms are domain general. For instance, although most studies in artificial grammar learning involve consonant letters, a large variety of other stimuli have been used occasionally, such as geometric forms, colors, and sounds differing by their timbre or their pitch, without noticeable difference. Conway and Christiansen (2005) directly compared touch, vision, and audition, and found many commonalities, although sequential learning in the auditory modality seemed easier than with the other two senses. Likewise, data on word segmentation have been successfully replicated with tones instead of syllables (e.g., Saffran et al., 1999; Saffran, 2002).

However, the fact that IL processes have a high level of generality across and within sensory modalities does not mean that they apply equally well to any stimuli, as if statistical learning mechanisms were blind to the nature of processed material. The well-known difficulty of publishing null results certainly accounts for a part of the apparent universality of IL mechanisms. A closer look shows, for instance, that learning may depend on aspects of the material that could seem *a priori* irrelevant. For instance, there is overwhelming evidence of rapid learning in standard SRT tasks, in which a target appears in successive trials at one of a few discrete locations. Chambaron et al. (2006) explored a similar situation, except that participants had to track a target that moved along a continuous dimension. They fail to obtain evidence of learning in several experiments, hence showing that, in spite of a close parallel between continuous tracking tasks and SRT tasks, taking benefit from the repetition of a segment in continuous tracking task appears to be considerably more difficult than taking benefit from the repetition of a sequence in SRT tasks. Moreover, recent research on statistical learning has shown that learning was highly dependent on low-level perceptual constraints. For instance, for a given statistical structure, the acoustic properties of the artificial speechflow have been shown to be determinant for learning to segment the speechflow into words (e.g., Onnis et al., 2005). Shukla et al. (2007) provides evidence that possible world-like sequences, namely chunks of three syllables with high transition probabilities, are not recognized as words if they straddle two prosodic constituents.

The efficiency of learning may also depend on high-level expectancies about the structure of the material. For instance, Pothos (2005) used an artificial grammar learning task in which the consonant letters were replaced by the name of cities. The sequences of cities were presented as the routes a salesman has to travel. In one group of participants, the training sequences matched the intuitive expectation that the salesman follows routes that link nearby cities, while in a second group, they conflicted with this intuition. Learning, as assessed by the comparison with an adequate control group, occurred only in the first group, as if a conflict between the knowledge acquired by processing the statistical structure of the stimuli and the intuitive expectations about stimulus structure prevented learning from occurring in the second group.

#### *2.32.3.1.5 About the learners*

Any discussion about learnability is meaningless without considering the characteristics of the learners. Most of the studies reported above have been performed on healthy adult participants.

Regarding first the effect of age, recent research on statistical learning has shown the surprising learning abilities of infants. These abilities have been initially revealed with auditory artificial languages (e.g., Saffran et al., 1996), but they are in no way limited to language-like stimuli. They concern sounds or combinations of visual features as well (e.g., Fiser and Aslin, 2001, 2002). Several studies have also investigated IL in children. They suggest that there is no noticeable evolution from 4- or 5-year-old children to young adults (e.g., Meulemans et al., 1998; Vinter and Detable, 2003; Karatekin et al., 2006). Other studies suggest that IL does not decline with healthy aging (e.g., Cherry and Stadler, 1995; Negash et al., 2003). Furthermore, a number of studies have reported impressive IL abilities in children (e.g., Detable and Vinter, 2004) and young adults (Atwell et al., 2003) with mental retardation, and in patients with psychiatric (e.g., Schwartz et al., 2003) and neurological disorders, including amnesia (e.g., Meulemans and Van der Linden, 2003; Shanks et al., 2006), Alzheimer's disease (Eldridge et al., 2002), Parkinson's disease (e.g., Smith and McDowall, 2006), closed-head injury (e.g., Vakil et al., 2002), and Williams Syndrome (Don et al., 2003). Statistical learning abilities have been shown in animals such as nonhuman primates (e.g., Hauser et al., 2001) or even rats (Toro and Trobalon, 2005).

These data have crucial implications for a number of fundamental and applied issues. They do not mean, however, that everyone shares equivalent abilities whenever statistical learning is concerned. In fact, comparative studies often select situations the difficulty of which is *a priori* well-suited for the full span of the investigated population. When the level of difficulty is increased, a difference often emerges. For instance, a deficit of performance has been observed in complex IL tasks in elderly people (e.g., Howard et al., 2004) and in amnesic patients (Curran, 1997; Channon et al., 2002). This dependency of IL with regard to learner's general competencies whenever the learning settings become complex enough is confirmed by studies on adult healthy people. For instance, Dienes and Longuet-Higgins (2004) observed that only participants experienced with atonal music were able to learn artificial regularities following the structures of serialist music.

### 2.32.3.2 Statistical Computations and Chunk Formation

#### *2.32.3.2.1 Computing statistics?*

Observing that performances in IL tasks conforms to statistical regularities may lead us to infer that learners compute statistics. Certainly, the idea that learners unconsciously compute statistics using the same algorithms as a statistician would use is somewhat implausible. However, the possibility of approximating the outcome of analytical computations through connectionist networks (e.g., Redington and Chater, 1998) offers a much more appealing alternative. Learning is performed by the progressive tuning of the connection weights between units within multilayer networks. Although different types of networks have been used (see Dienes, 1992), the Simple Recurrent Networks (SRN), initially proposed by Elman (1990), have been the most widely applied to IL. SRNs are typically trained to predict the next element of sequences presented one element at a time. Cleeremans and McClelland (1991) have shown that an SRN was able to simulate the performance of human learners in an SRT task in which the successive locations of the target were generated by a finite-state grammar, and the ability of SRNs to successfully account for performance in various IL paradigms has been confirmed since then in a number of studies (e.g., Kinder and Assmann, 2000). Certainly, due to the impressive ability of connectionist networks to simulate learner's performance, the idea that learners actually perform statistical computations is taken for granted by a number of authors. This idea is not compelling however. Inferring statistical computation from statistical sensitivity may amount to repeating the same error as the early researchers in IL, who inferred rule abstraction from the behavioral sensitivity to rules. An alternative interpretation emerges from the observation that IL generally leads to the formation of chunks.

#### *2.32.3.2.2 The formation of chunks*

The fact that learning leads to the formation of chunks is largely consensual. This is obviously the case in recent studies on word segmentation and object formation, in which performance is directly assessed through chunk formation. But this is also true in most of the other situations of IL, in which chunks are not the explicit end-product of learning. A number of studies have shown that participants learn small chunks of two or three elements in artificial grammar learning settings. Chunking the material, far from being a degraded procedure, is a highly efficient mode of coding. Indeed, dealing with small units facilitates transfer and generalization. This happens because, given the structure of finite-state grammars, new items are formed by recombining old components. However, this is true only if the chunks respect the statistical structure of the material. To put the matter simply, assuming five events (A, B, C, D, and E), forming the chunks 'AB' and 'CDE' is beneficial only if A and B on the one hand, and C, D, and E on the other hand, form cohesive structures. If 'AB' is frequently followed by C, and 'DE' frequently occurs in other contexts, then this mode of chunking would be ill suited (Perruchet et al., 2002).

The formation of chunks forming cohesive structures can be easily accounted for by the idea that learners compute statistics. For instance, for Saffran and Wilson (2003), verbal chunks are inferred from statistical computations and then serve as the stuff for further statistical computations. Fiser and Aslin (2005) also consider that the visual input is chunked into components according to the statistical coherence of their components. To use the five-event example, AB and CDE would emerge as from some kind of cluster or factorial analyses once the correlational structure of the events has been computed.

#### *2.32.3.2.3 Are statistical computations a necessary prerequisite?*

Chunks consistent with the statistical structure of the material can also emerge without prior statistical computations. Simple memory mechanisms could be sufficient. To begin with, let us consider the ubiquitous phenomenon of forgetting. Because frequently repeated events tends to be forgotten to a lesser extent than less frequent events, forgetting leads us to be sensitive to event frequency, without any statistical 'computation.' Several models of IL (Servan-Schreiber and Anderson, 1990; Knowlton and Squire, 1996; Perruchet and Vinter, 1998a) rest on this intuition. Again, in the example, the chunks 'AB' and 'CDE' would emerge from the fact that A and B on the one hand, and C, D, and E on the other hand, occur more often together than any other combinations of events. In Perruchet and Vinter's Parser model, those chunks emerge simply because other associations of events (such as ABC), if they occur, are forgotten due to their relative rarity. The difference with the statistical account is that, instead of being inferred from the results of statistical computation, chunk formation is the primary mechanism, and the cohesive chunks are those that are selected among a number of other ones due to well-known laws of associative memory, primarily forgetting.

Chunking is often thought of as exclusively sensitive to the raw frequency. This would indeed be the case if the strength of memory traces only depended on the repetitions of events. However, it has long been known that forgetting is due in large part to the interference generated by the prior or subsequent events that are related in some way to the target event. Now, and this is the crucial point, taking into account the effect of interference in chunk formation amounts to considering other measures of association than the raw frequency of co-occurrences. For instance, implementing forward interference is sufficient to make chunk strength sensitive to transitional probabilities (Perruchet and Pacton, 2006, Box 3). Moreover, Perruchet and Peereman (2004) have shown that the Perruchet and Vinter's (1998a) Parser model, thanks to the role ascribed to interference in chunk formation, was even sensitive to contingency, that is, to a measure of association more comprehensive than conditional probabilities.

To recap, the current debate is between those who argue that statistical computations are performed first, with the chunks inferred on the basis of their results, and those who argue that the chunks are formed from the outset, with the sensitivity to statistical regularities being a by-product of the selection of those chunks as a consequence of ubiquitous memory laws. Note that the two interpretations are equally consistent with associative learning principles. One advantage of the second option is its parsimony. Indeed, no additional computational devices have to be imagined to extract chunks from distributional information. In addition, the chunk model can be easily unified with the instance-based model, because both are grounded on standard memory laws. A unified view could find an integrative framework in the so-called processing account of IL. This account borrows, from research in memory, the idea that memory traces are no more than the by-product of the processing operations engaged during study, and that retrieval depends on the overlap between the processing undertaken during the study and the test phase (e.g., Roediger et al., 1989). Support for this view in IL studies stems from the demonstration of the encoding specificity effects in research into artificial grammar. For instance, Whittlesea and Dorken (1993) show that performances in the test phase are better if the processing involved during the test (pronouncing or spelling the letter strings) matches the processing involved during the study phase. Although the processing account is historically associated with the instance-based models of IL (e.g., Neal and Hesketh, 1997), its grounding principles could be applied to chunk-based models as well.

These considerations, however, cannot be considered as compelling. At this time, the available experimental studies intended to tease apart the predictions from statistical and chunk-based models have produced equivocal results (e.g., Boucher and Dienes, 2003). Clearly, the outcome of the debate is pending further empirical investigations.

## 2.32.4 How Implicit Is 'Implicit Learning'?

What defines implicitness in IL is far from being agreed upon. A distinction is made, in the following sections, between what occurs during the training phase and the test phase of an IL session. The study-test distinction has limited interest, insofar as in most real-world situations, and in several laboratory situations (such as SRT tasks) as well, any event both influences subsequent events and is itself influenced by the prior ones, hence serving the two functions simultaneously. However, this distinction provides a convenient means to tease apart different issues.

### 2.32.4.1 Implicitness during the Training Phase

#### *2.32.4.1.1 Incidental and intentional learning*

A feature which is a part of virtually all definitions of IL is the incidental nature of the acquisition process. IL proceeds without people's intention to learn. This characteristic is sometimes the only one to be retained, thus conflating the notion of IL and incidental learning (e.g., Stadler and French, 1994). The SRT tasks are often considered as those that offer the best guarantee of the incidental nature of learning, because this task is endowed with its own internal purpose, and it leaves quite limited time for thinking about the task structure. In most of the other IL tasks, instructions distract participants from thinking about the overall material structure, by focusing participants' attention on individual items. For instance, in artificial grammar learning, participants are generally asked for the rote learning of individual letter strings. In invariant learning, participants are asked to perform some arithmetic computation on each digit string. In other tasks, such as the word-segmentation task, participants are simply asked to listen to the artificial language, without specific demands.

#### *2.32.4.1.2 Is attention necessary?*

A question of major interest is whether performance improvement depends on the amount of attention paid to the study material during the familiarization phase. The main strategy consists in adding a concurrent secondary task during the training session, then observing whether performance improvement is equivalent to that observed in a standard procedure.

A few early studies claimed that the addition of a secondary task had no effect, or even could *facilitate* learning in very complex experimental settings. This leads to contrast the concepts of 'selective learning' and 'unselective learning' (e.g., Berry and Broadbent, 1988), with the latter being assumed to occur when the situation was too complex to be solved by attention-based mechanisms. The original results were not replicated, however (e.g., Green and Shanks, 1993), and to the best of our knowledge, the notion of unselective learning, as initially discussed in the studies conducted by Broadbent and colleagues, is no longer advocated.

The idea of two forms of learning, differing according to whether attention is required or not, has also been proposed in another context, but with the opposite stance. The hypothesis was that attention is required for learning complex sequences in SRT tasks, while nonattentional learning is efficient for the simplest forms of sequential dependencies (Cohen et al., 1990). However, observing learning under dual-tasks conditions does not imply the existence of a nonattentional form of learning, because the secondary task might not deplete the attentional resources completely (Stadler, 1995). Closing their survey on the role of attention in implicit sequence learning, Hsiao and Reber concluded:

> We view sequence learning as occurring in background of the residual attention after the cost of the tone-counting task [commonly used as a secondary task in this context] and the key-pressing task. If there is still sufficient attention available to the encoding of the sequence, learning will be successful; otherwise, failure will result. (Hsiao and Reber, 1998: 487)

Regarding artificial grammars, Reber (e.g., 1993) has also acknowledged that attention to the study material is necessary for learning to occur. In support of this claim, Dienes et al. (1991) have shown that the accuracy of grammaticality judgments was lowered when subjects had to perform a concurrent random number generation task during the familiarization phase.

Note also that other studies have shown that, without at least minimal attentional involvement, even simple covariations or regularities turn out to be impossible to learn (Jimenez and Mendez, 1999; Hoffmann and Sebald, 2005; Pacton and Perruchet, in press; Rowland and Shanks, 2006b). The conclusion according to which improved performance in IL situation requires attention has been recently supported by studies on statistical learning using continuous speech flow (Toro et al., 2005) or visual displays (Baker et al., 2005; Turk-Browne et al., 2005). This conclusion comes as no surprise, because the major role played by selective attention in acquisition processes is an old and robust empirical finding (for another approach that emphasizes the role of attention, see Frensch et al., 1994).

## 2.32.4.2 Implicitness during the Test Phase

### *2.32.4.2.1 The lack of conscious knowledge about the study material*

Is it possible to improve his/her performance without being conscious of what has been learned? A considerable amount of studies have addressed this question by exploring participants' explicit knowledge through postexperimental tests. Overall, a number of studies report that participants are aware of the knowledge they have acquired. However, other studies report that participants fail in the test of explicit knowledge. The question is: Are those negative results reliable? A number of potential drawbacks have been raised.

### *2.32.4.2.2 The Shanks and St. John information criterion*

The first problem is linked to the fact that exploring whether knowledge is consciously represented primarily requires that the knowledge relevant for performing the task has been correctly identified. In an influential synthesis of the literature, Shanks and St. John (1994) coined this requirement as the 'information criterion.' The information criterion stipulates that the information the experimenter is looking for in the awareness test needs to match the information responsible for the performance change.

Although the cogency of this criterion may seem obvious, it must be realized that it entails that any conclusion about implicitness entirely depends on the response given to the 'what is learned' question raised in the prior sections. Any error in the hypothesized content of knowledge, far from being a "slightly embarrassing methodological glitch" (Reber, 1993, note p. 44, 114-115), has dramatic consequences on the inference that one may drawn about the implicit/explicit status of the acquired knowledge. For instance, Reber and Allen correctly pointed out that:

> . . . clearly a considerable proportion of subjects' articulated knowledge can be characterized as an awareness of permissible and nonpermissible letter pairs. (Reber and Allen, 1978: 210).

However, the authors did not realize that this form of knowledge was sufficient to account for performance. Instead, they attributed performance improvement to rule knowledge, which they concluded to be the result of unconscious abstraction. A large part of the earlier claims for the lack of conscious knowledge about the study material seemingly stems from this problem, also known as the problem of the 'correlated hypotheses' after the seminal studies by Dulany (1961) and Dulany et al. (1984).

### *2.32.4.2.3 The Shanks and St. John sensitivity criterion*

According to Shanks and St. John, a second criterion is that the test of explicit knowledge is sensitive to all of the relevant conscious knowledge. A test of free recall, such as used in the early studies on IL, is notoriously insensitive. For instance, participants may not report some knowledge they have about the material structure, because they have a conservative response criterion that makes them respond only when their knowledge is held with high confidence, or simply because they think this knowledge is irrelevant or trivial. For this reason, most studies now involve a test of recognition, in which participants have to discriminate items belonging to the training materials from new items. However, performing no better than chance in a recognition test is not necessarily a proof that participants lack any explicit knowledge about the task. For instance, Reed and Johnson (1994) used a recognition test after an SRT task and observed that recognition scores were at chance. In an attempted replication involving the same procedure, Shanks and Johnstone (1999) found instead very high levels of recognition. The only difference between the two studies was that participants in Shanks and Johnstone were rewarded by an extra sum of money for each correct decision. Performing the recognition test is somewhat tedious, and presumably participants in the Reed and Johnson study were not motivated enough to make the effort required to perform the task correctly.

#### 2.32.4.2.4 The problems of forgetting

In the standard procedure, the explicit tests are postponed after the task of IL, thus raising the problem of the retention of the knowledge exploited during the implicit test. For instance, Destrebecqz and Cleeremans (2001) reported chance-level recognition in an SRT paradigm (at least for a group of participants). Notably, the test of recognition was administered after participants had performed another task, in which they had to generate sequences under various instructions (see below). Shanks et al. (2003) attempted to reproduce Destrebecqz and Cleeremans' dissociation between RT measures and recognition scores, but in conditions in which the two kinds of measures were taken concurrently. In three experiments, they failed to replicate the Destrebecqz and Cleeremans' dissociation and obtained instead clear evidence of recognition. Note that the problems of forgetting are made especially important due to the fact that a recognition test necessarily includes the exposure to new sequences (generally half of the test items). Because these new sequences are highly similar to old sequences, they are prone to generate interference for the subsequent test trials.

#### 2.32.4.2.5 The problem of the reliability of measures

The scores in implicit and explicit tasks are often found to be correlated. For instance, in SRT tasks, Perruchet and Amorim (1992) reported that Pearson correlations over the sequence trials between RT and recognition scores ranged, in three experiments, from .63 to .98. However, some authors (e.g., Willingham et al., 1993) have argued that evidence for unconscious knowledge was given by the fact that learning could be still observed when the analysis was restricted to the subgroup of items (or the subgroup of participants) for which no evidence of explicit knowledge was gathered. This argument is questionable, however. As discussed in Perruchet and Amorim (1992), the method, in effect, dichotomizes the scores on the implicit measure on the one hand, and on the explicit measure on the other, to assign the items or the participants to a fourfold contingency table. Then inference for dissociation is drawn from the observation that some items or some participants fall into the discordant cells of the contingency table, or in other words, that the correlation is not perfect. The problem with this method is that a prerequisite for obtaining a perfect correlation is perfect reliability of measures. This condition is highly unrealistic for psychological measures, especially for the scores on implicit tests (Meier and Perrig, 2000; Buchner and Brandt, 2003). Shanks and Perruchet (2002) have developed this reasoning into a quantitative model, which assumes that the sources of error plaguing implicit and explicit measure are independent. Although the model involved a single underlying memory variable, it turned out to be able to generate a dissociation between RTs and recognition in SRT tasks that mimics fairly well the dissociation the authors reported themselves (despite the temporal synchrony of measures).

#### 2.32.4.2.6 An intractable issue?

To sum up, the current evidence for the lack of conscious knowledge about the study material is weak at best. There is currently no identified condition allowing one to obtain a reproducible dissociation. Most of the experiments reporting above-chance performance in implicit measures and chance-level performance in explicit tests have been replicated in more stringent conditions, and it turns out that, as a rule, the dissociation no longer appears when appropriate controls are made.

These data do not allow clear conclusions. On the one hand, the preceding discussion makes it clear that it is impossible to conclude to the existence of learning without any conscious counterpart. But, on the other hand, it should be also unwarranted to infer from the current findings that conscious awareness of the material structure is necessary for performance improvement. The first reason is a logical one, which has been met with regard to rule abstraction, namely, it is not possible to prove that something does not exist. There is yet another reason, linked to the fact that no task is process-pure, as has been well documented in the literature on implicit memory. This is especially true for the most sensitive tests, such as recognition. Jacoby (1983), and many others since, have argued that the relative fluency of perception, which relies on implicit process, may be used as a cue for discriminating old from new items in a recognition task, thus making a variable contribution to recognition judgments over and beyond a directed memory search factor. This entails that above-chance recognition after an IL task does not provide a compelling evidence for explicit knowledge. To date, it is not clear how further studies could solve this conundrum. Some authors (e.g., Higham et al., 2000) have suggested that those problems are intractable and should prompt researchers to give up any attempts to demonstrate learning without concurrent consciousness.

#### 2.32.4.2.7 The subjective measures

The measures discussed so far are often called 'objective,' because it is the experimenter that judges the level of awareness of participants from their performance in specific tests. Another way of defining implicitness starts from the consideration of the phenomenal state of the participants such as it may be directly expressed. Two such 'subjective' measures of implicitness have been proposed in the literature, the guessing criterion and the zero-correlation criterion (Dienes et al., 1995). In both cases, participants are submitted to a test of explicit knowledge such as a recognition test, and they have to rate how confident they are about each decision. To check whether the guessing criterion is filled, the scores on the recognition test are restricted to those of the decisions that are accompanied by a subjective experience of guessing. If participants achieve above-chance discrimination while they report to be guessing, the guessing criterion is met. The zero-correlation criterion rests on the idea that, if knowledge is implicit, participants must not be more confident when they are correct than when they are incorrect. As a consequence, if participants have no introspection into the bases of their decisions, the correlation between confidence and accuracy should be null.

Can performances on standard IL tasks be called implicit according to these criteria? The literature again does not provide a clear response, with some studies reporting positive results and others negative results. In fact, the general picture appears similar to that observed with objective measures, with initially positive findings being not replicated when more sensitive measures are used. For instance, Dienes and Altman (1997) reported a zero correlation between confidence and accuracy in an artificial grammar learning task involving a transfer paradigm. Notably, participants had to assess their confidence on a continuous scale ranging from 50 to 100, where 50 was a complete guess and 100 was absolutely sure. Using the same scale, Tunney and Shanks (2003b) replicated this result. However, based on a study by Kunimoto et al. (2001), Tunney and Shanks reasoned that a binary confidence judgment could be more sensitive, maybe because participants might find it easier to express subjective states on a binary than on a continuous scale. When participants had to express their confidence on a binary scale, they were found to be systematically more confident in their correct decision than in their incorrect decision in several independent experiments. To conclude, irrespective of the *a priori* validity that one decides to ascribe to subjective measure of implicitness, it appears that there is to date no identified procedure that fulfills subjective criteria in a reproducible way.

#### 2.32.4.2.8 The lack of control

One possible meaning of 'implicitness' is that of 'automaticity.' One of the key features usually attributed to automatic behavior is that it is irrepressible, irrespective of people's intentions to do so. Although recent literature on automaticity has questioned the possibility that any learned behavior - even reading, which is often construed as prototypical of automaticity – could actually be outside of control (e.g., Tzelgov et al., 1992), the question of whether the expression of knowledge in IL tasks shares this property deserves to be raised. Such a demonstration was provided by Destrebecqz and Cleeremans (2001) in an SRT task. In an application of Jacoby's process dissociation procedure (Jacoby, 1991) to this task, the authors asked participants to generate a sequence under two successive conditions during the test phase of an otherwise standard SRT procedure. In the first condition, they were told to generate the sequences they were previously exposed to, and if they fail to remember them, to generate sequences as they come to their minds (the inclusion instructions). Then participants had to produce a sequence of key-presses that did not overlap with the training sequence (the exclusion instructions). Crucially, participants - at least a subgroup of participants trained without any interval between the response to a target and the appearance of the next target - were influenced by the training sequences despite their intention to prevent this from happening. They performed in the same ways irrespective of the instructions, and under exclusion instructions, they generated the training sequence more than would be expected from an appropriate baseline.

These findings, however, have proven to be difficult to replicate. In the same conditions, Wilkinson and Shanks (2004) found that participants were more influenced by the training sequence under inclusion than under exclusion instructions (see also Destrebecqz and Cleeremans, 2003). In three experiments, Wilkinson and Shanks also failed to replicate the results according to which parts of the training sequence were generated more often under exclusion instructions than in the baseline, even after more extensive training than used by Destrebecqz and Cleeremans (2001) - although they did not get any negative difference either, as it could be expected if participants were able to withdraw the parts of the training sequence from influencing their production. Overall, these and others results (see for instance Dienes et al., 1995; Tunney and Shanks, 2003a) offer only quite limited evidence for the conclusion that knowledge gained in IL settings lies outside of intentional control.

#### 2.32.4.2.9 The lack of intentional exploitation of acquired knowledge

The fact that participants are seemingly able to withdraw the influence of prior training when they are asked to do so does not mean that, under standard conditions, this influence is intentionally mediated. The lack of intentional exploitation of stored knowledge seems to be a hallmark of the real-world examples given at the outset of this chapter. Presumably nobody has the intuition of applying strategically a core of learned knowledge when speaking his maternal language, hearing music, or conforming to physical or social rules. Is this intuition confirmed in experimental studies?

The question is made difficult by the fact that, in most cases, influences expected from the intentional exploitation of conscious knowledge about the relevant aspects of the situation would have the very same effects as those induced by unconscious processes. As a consequence, it has been suggested that performance in IL tests can be accounted for by the use of explicit knowledge about various aspects of the experimental situation (Dulany et al., 1984; Shanks and St. John, 1994). It is certainly impossible to rule out this contention in general. However, it should be unwarranted to generalize it to all IL tasks. Indeed, there are cases in which the conscious exploitation of explicit knowledge does not coincide with the expected results of unconscious processing. One example is provided by the grammar learning studies involving preference judgments. Indeed, there should be *a priori* no reason for the knowledge about the material to be used to guide a preference judgment. However, participants consistently prefer grammatical items (e.g., Manza et al., 1998).

Vinter and Perruchet (2000) proposed a new task of IL that was especially devised to eliminate the potential influence of intentional control. When adults are asked to draw a closed geometrical figure such as a circle, their production exhibits a striking regularity. If they begin the circle in the lower half, they tend to rotate clockwise, and if they begin the circle in the upper half, they tend to rotate counter clockwise. In Vinter and Perruchet experiments, participants were guided to draw geometrical figures in such a way that this natural covariation was inverted. This training induced important and long-lasting modifications of subsequent free drawings. The point of interest is that, even if participants had become aware of the inverted covariation between the starting point and the rotation direction they experienced during the training session, they should have no reason to modify their usual mode of drawing as they did. This study provides clear evidence for an adaptive mode in which subjects' behavior becomes sensitive to the structural features of an experienced situation, without the adaptation being due to the intentional exploitation of subjects' explicit knowledge about these features.

### 2.32.4.3 Processing Fluency and Conscious Experience

Let us now reverse the direction of the potential relation between learning mechanisms and conscious thought, in order to examine the level of dependency of conscious thought with regard to IL.

An influential model of how training in IL settings leads to a change in performance posits that training induces a modification in the subjective experience of the learner. More specifically, the underlying idea is that training improves the fluency of perceptual processing for the studied materials. This account was initially proposed by Servan-Schreiber and Anderson (1990) in the context of their chunking theory. In fact, however, the improved processing fluency can also be attributed to other forms of knowledge, such as rules or memory for specific instances. Thus a fluency theory has been advocated as well by those researchers who maintain a role for rule-based processing (Zizak and Reber, 2004) and by those who consider that statistical computations are sufficient (e.g., Conway and Christiansen, 2005).

Let us examine how this account works in artificial grammar learning paradigms. The assumption is that, after training with a sample of grammatical strings of letters, new grammatical strings are processed fluently, or more precisely, more fluently than expected (Whittlesea and Williams, 2000), hence generating a feeling of familiarity leading itself to endorse the strings as grammatical. The two steps of this hypothesis have received experimental support. The fact that exposure to the training strings improved processing fluency has been shown by Buchner (1994). The test strings were displayed in such a way that they emerged progressively from noise, a procedure known as a perceptual clarification procedure. It turned out that grammatical strings were identified about 200 ms faster than ungrammatical ones. The fact that improved fluency in turn influences grammaticality judgments has been demonstrated using a method well documented in the literature on implicit memory, which consists in artificially enhancing the fluency of processing of selected items. During the test phase of an otherwise standard artificial grammar learning experiments, Kinder et al. (2003) exposed participants to test strings that did not differ in their grammatical status (they were all grammatical). The test strings were displayed in a perceptual clarification procedure as in Buchner (1994), except that some strings were clarified slightly faster than the others. Participants judged the former more often grammatical than the latter.

The fluency account suggests that IL modifies the subjective experience of the learner. However, the induced modifications appear to be quite minor, insofar as they are prompted by a gain of some fractions of second in processing speed. The frequent rapprochement of the concepts of IL and priming (e.g., Cleeremans et al., 1998; Conway and Christiansen, 2006; Kinder et al., 2003) is consonant with the idea that the training-induced modifications are relatively inconsequential. It is also possible to consider that the changes in the conscious experience of the learner are much more striking. For instance, in artificial grammar learning, participants normally learn to perceive the grammatical strings as a sequence of chunks the content of which is consonant with the structure of the grammar (e.g., the sequences of letters composing a recursive loop have high chance of being perceived as chunks, see Servan-Schreiber and Anderson, 1990; Perruchet et al., 2002). Likewise, in word-segmentation studies, the speechflow, which is initially perceived as an unorganized set of syllables, turns out to be perceived as a sequence of units, which match the words composing the language. More generally, an essential function of IL could be that of making the conscious perception and representation of the world isomorphic with world's deep structure. Because this change in subjective experience can be construed as a simple by-product of the attentional processing of the incoming information, Perruchet and Vinter (2002) have suggested the concept of 'self-organizing consciousness' to express the idea that IL shapes new conscious percepts and representations in a way which make them increasingly adaptive (see also Perruchet, 2005; Perruchet et al., 1997).

Neither the fluency account nor Perruchet and Vinter's (2002) self-organizing consciousness model is aimed to account for all behavioral changes observed in IL settings. For instance, although the fluency account is relatively consensual (partly due to the fact that it is mute with regard to the nature of knowledge inducing fluency), this account explains only a part of the performances observed in IL settings. Even in the artificial grammar learning paradigm, which is *a priori* a well-suited field of application, relative processing fluency does not seem to be able to account for the whole pattern of grammaticality judgments (Buchner, 1994; see also Zizak and Reber, 2004, p.23). However, these models point to the possibility of considering IL and consciousness not in terms of dissociation or independence, but rather in terms of dynamic interplay.

### 2.32.4.4 Summary and Discussion

To sum up, research of the last few decades has shown that it is surprisingly difficult to specify in what sense IL is implicit. The notion of unselective, nonattentional learning has vanished in light of studies demonstrating that learning requires at least some forms of attentional processing of the incoming information. Likewise, there are quite limited supports to claim that while they perform the implicit test participants (1) have no conscious knowledge about the study material, (2) have the subjective experience of guessing, or (3) have no control over the expression of their knowledge. Of course, it is possible to include one or the other of these features within a definition of IL, and some authors did so (for a sample of definitions, see Frensch, 1998). However, endorsing this kind of definition leads to the somewhat paradoxical consequence of giving to a research domain the objective of checking whether this domain actually exists. To date, there is no specified paradigm in which one or the other of these criteria can be asserted in a consensual and reproducible way.

A feature that can be retained with higher confidence is the lack of intentional exploitation of stored knowledge. This does not mean, obviously, that this condition is fulfilled in each and every study, but rather that the existence of the phenomenon can be reasonably asserted on the basis of reproducible evidence. Accepting the role of unconscious influences, however, does not lead us to conceive IL and conscious experiences as divorced one from each other. There is indeed extnsive evidence that these unconscious influences primarily affect the conscious experience of the learner.

## 2.32.5 Implicit Learning in Real-World Settings

### 2.32.5.1 Exploiting the Properties of Real-World Situations

Although most of research on IL uses artificial, laboratory situations, natural situations have been used on occasion to shed light on specific issues. In this case, only the test phase is carried out in well-controlled experimental conditions, while implicit training is assumed to have occurred previously in natural settings. For instance, Pacton et al. (2001) exploited the very extended time scale on which real-world learning takes place to examine whether transfer decrement (see the section titled 'The phenomenon of transfer: the interpretations') is a transitory or an enduring phenomenon. The issue is important, because it can be argued that the transfer decrement commonly observed in laboratory settings, which is one of the arguments used against a rule-based view, is simply due to the fact that training is not extensive enough to allow the full development of rule abstraction. Pacton et al. explored the development of the sensitivity to certain orthographic regularities not explicitly taught at school. They showed that the decrement in performance due to transfer persisted without any trend toward fading over the 5 years of experience with printed language that they examined, hence strengthening the claim that IL is not mediated by rule knowledge.

### 2.32.5.2 Exploiting our Knowledge about Implicit Learning

The knowledge gained in laboratory studies is aimed at improving our understanding of world-sized issues. Explicit loans from the IL literature have been made occasionally in a number of domains, including child development (Perruchet and Vinter, 1998b), second-language acquisition (e.g., Ellis, 1994; Robinson, 2002), spelling acquisition (Kemp and Bryant, 2003; Pacton et al., 2005; Pacton and Deacon, in press), and the development of gustatory preferences (Brunstrom, 2004). To various degrees, the concepts and the methodology of laboratory studies have inspired researchers to progress in the understanding of these domains. In regard of the potential relevance of IL mechanisms in these and other domains, much more could be made in this direction, however. The only domain in which a sizeable amount of literature has emerged concerns the relationships between IL and natural language acquisition (e.g., Gomez and Gerken, 2000). This rapprochement is partly due to the fact that research on language has evolved on its own toward methods – the use of artificial languages – and concepts – notably around the notion of statistical learning – that are also at the heart of IL research.

The practical applications of IL, for instance for educative purposes or the reeducation of neurological patients, appear to be still sparser. Some methods have evolved that exploit principles which can be *a posteriori* related to IL principles, such as using conditions as similar as possible to natural learning to teach second language (after Krashen, 1981) or reading (for a review, see Graham, 2000). An extensive literature also concern the use of errorless learning for reeducative purposes in a neuropsychological perspective (see review in Fillingham et al., 2003). But most of these attempts have been conducted without considering the possible contribution of IL research (for a recent exception, see Saetrevik et al., 2006). The explanations for this relative paucity are certainly manifold. One of them may be that learning in real-world situations most often involve some mixture of implicit (or incidental) and explicit (or intentional) learning. Now, the interactions between these forms of learning have not been at focus in the literature on IL, because, except in a few studies (e.g., Matthews et al., 1989), the objective has been to isolate implicit processes to examine them in their maximum state of purity. Further studies are needed to assess how, for instance, the learning of rules in explicit conditions may be combined with implicit statistical learning.

## 2.32.6 Discussion: About Nativism and Empiricism

Let us return to a question raised at the outset of this chapter, which stemmed from the lack of consideration during the behaviorist era of issues such as first-language acquisition, category elaboration, sensitivity to musical structure, acquisition of knowledge about the physical world, and various social skills. It was pointed out that this situation opened the door to the upsurge of a nativist perspective. Where do the studies reported in this chapter leave us?

At first glance, the mechanisms of IL, as they are revealed in laboratory studies, appear as definitely underpowered. The picture given by recent research stands far from the idea of the extraordinarily powerful processes that were imagined once, for instance by Lewicki et al., when they contended that “our non-conscious operating processing algorithms can do instantly and without external help” the same job as our conscious thinking achieves in relying on “notes (with flowchart or lists of if-then statements) or computer” (Lewicki et al., 1992, p.798). In fact, IL processes are probably unable to bring out to genuine rule knowledge, and the possibility of transfer are limited. In addition, the involvement of these processes seems to be dependent on selective attention. As pointed out above, the experimental study of learning around the 1960s was essentially devoted to classical and operant conditioning on the one hand and to the formation of concepts or problem-solving processes on the other hand. To make a long story short, IL mechanisms seem to be much nearer to the former than to the latter.

To be sure, experimental studies show that participants generally perform above chance in complex experimental settings. However, above-chance performance is generally attributable to the learning of some indirect, correlated aspects, which can be easily captured by elementary mechanisms. Everything happens as if IL often captured only nonessential aspects of the task. In experimental contexts, these correlated features are often considered as potential drawbacks, which need to be eliminated to reach the deep substance of the training material. For instance, studies in artificial grammar learning are often designed in such a way that bigram distribution becomes noninformative, studies in invariant learning often are controlled in such a way that the repetition of digits brings out no information about the invariant, and so on.

On the face of it, these data seem to provide fuel for a perspective in which the role of learning is minimized with regard to innate abilities. This is indeed the case if one considers that the knowledge base underlying the mastery of language and of the other high-level abilities alluded to above should be of the same form as the knowledge base that the scientist - for instance the linguist - acquires from an analytic investigation into his or her domain, that is, a formal, rule-based set of principles. This form of knowledge seems indeed to be definitely out of reach of IL processes.

However, a quite different perspective is possible. The general idea consists in assuming that learning in real-world setting proceeds as in the laboratory, that is, through the capture of correlated, apparently secondary aspects that can be grasped by elementary associative processes and that allow a good approximation of the behavior that would result from the knowledge of the formal structure of the domain. In order to be viable, such a perspective requires that the objective analysis of specific domains provides evidence for such correlated features. Quite interestingly, recent research on language has revealed a number of such features. The best-documented example is certainly the past-tense formation in English, in which it has been shown that regular and irregular verbs differ according to the distribution of their phonological and semantic features. Connectionist simulations have shown that exploiting those correlated cues leads to a very good approximation of the performance that would result from the formal knowledge of the *-ed* suffix rule, along with the knowledge of the exceptions (e.g., McClelland and Patterson, 2002). To consider another illustration, it has been shown that simple co-occurrence statistics (e.g., Redington et al., 1998) as well as phonological cues (e.g., Monaghan et al.,

2005) turn out to be highly informative about grammatical categories. These and other studies suggest that, as far as language is concerned, abstract classes and categories are often associated with simple statistical properties that make them tractable by general-purpose statistical learning mechanisms.

If further studies on language corpuses confirm and extend this kind of findings, and if the same kind of analysis proves to be successful in other high-level domains of competence, then IL mechanisms would appear extraordinarily powerful to promote behavioral adaptation. Indeed, those mechanisms are remarkably well-suited to exploit a massive amount of correlated cues. This approach appears to provide the first viable alternative to the nativist perspective that is still prevalent in the cognitive approach starting from Chomsky. The development of a full-blown empiricist alternative depends obviously upon further investigations on human learning processes, but also on the development of a nonconventional mode of description of the world humans are faced with.

## References


Altmann GTM and Dienes Z (1999) Rule learning by seven-month-old infants and neural networks. *Science* 284: 875.

Anderson JR (1994) *Rules of the Mind*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Aslin RN, Saffran JR, and Newport EL (1998) Computation of conditional probability statistics by 8-month-old infants. *Psychol. Sci.* 9: 321–324.

Atwell JA, Conners FA, and Merrill EC (2003) Implicit and explicit learning in young adults with mental retardation. *Amer. J. Ment. Retard.* 108: 56–68.

Baker CI, Olson CR, and Behrmann M (2005) Role of attention and perceptual grouping in visual statistical learning. *Psychol. Sci.* 15: 460–466.

Berry D (ed.) (1997) *How Implicit Is Implicit Learning?* Oxford: Oxford University Press.

Berry DC and Broadbent DE (1988) Interactive tasks and the implicit-explicit distinction. *Br. J. Psychol.* 79: 251–272.

Berry DC and Dienes Z (1993) *Implicit Learning: Theoretical and Empirical Issues*. Hillsdale NJ: Lawrence Erlbaum Associates.

Boucher L and Dienes Z (2003) Two ways of learning associations. *Cogn. Sci.* 27: 807–842.

Bright JEH and Burton M (1998) Ringing the changes: Where abstraction occurs in implicit learning. *Eur. J. Cogn. Psychol.* 10: 113–130.

Brooks LR (1978) Nonanalytic concept formation and memory for instances. In: Rosch E and Lloyd BB (eds.) *Cognition and Categorization*, pp. 169–211. Hillsdale NJ: Lawrence Erlbaum Associates.

Brooks LR and Vokey JR (1991) Abstract analogies and abstracted grammars: A comment on Reber and Mathews et al. *J. Exp. Psychol. Gen.* 120: 316–323.

Buchner A (1994) Indirect effects of synthetic grammar learning in an identification task. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 550–565.

Buchner A and Brandt M (2003) Further evidence for systematic reliability differences between explicit and implicit memory tests. *Q. J. Exp. Psychol.* 56A: 193–209.

Brunstrom JM (2004) Does dietary learning occur outside awareness? *Conscious. Cogn.* 13: 453–470.

Chambaron S, Ginhac D, Ferrel-Chapus C, and Perruchet P (2006) Implicit learning of a repeated segment in continuous tracking: A reappraisal. *Q. J. Exp. Psychol.* 59A: 845–854.

Channon S, Shanks D, Johnstone T, Vakili K, Chin J, and Sinclair E (2002) Implicit learning spared in amnesia? Rule abstraction and item familiarity in artificial grammar learning. *Neuropsychologia* 1404: 1–13.

Cherry KE and Stadler MA (1995) Implicit learning of a nonverbal sequence in younger and older adults. *Psychol. Aging* 10: 3793–3794.

Christiansen MH, Allen J, and Seidenberg MS (1998) Learning to segment speech using multiple cues: A connectionist model. *Lang. Cogn. Processes* 13: 221–268.

Christiansen MH and Curtin S (1999) Transfer of learning: Rule acquisition or statistical learning? *Trends Cogn. Sci.* 3: 289–290.

Chun MM and Jiang Y (2003) Implicit, long-term spatial contextual memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 224–234.

Cleeremans A and Jimenez L (1998) Implicit sequence learning: The truth is in the details. In: Stadler M and Frensch P (eds.) *Handbook of Implicit Learning*, pp. 323–364. Thousand Oaks, CA: Sage Publications.

Cleeremans A, Destrebecqz A, and Boyer M (1998) Implicit learning: News from the front. *Trends Cogn. Sci.* 2: 406–416.

Cleeremans A and McClelland JL (1991) Learning the structure of event sequences. *J. Exp. Psychol. Gen.* 120: 235–253.

Cock JJ, Berry DC, and Gaffan EA (1994) New strings for old: The role of similarity processing in an incidental learning task. *Q. J. Exp. Psychol.* 47: 1015–1034.

Cohen A, Ivry RI, and Keele SW (1990) Attention and structure in sequence learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 17–30.

Conway CM and Christiansen MH (2005) Modality-constrained statistical learning of tactile, visual, and auditory sequences. *J. Exp. Psychol. Learn. Mem. Cogn.* 31: 24–39.

Conway CM and Christiansen MH (2006) Statistical learning within and between modalities: Pitting abstract against stimulus-specific representations. *Psychol. Sci.* 17: 905–912.

Creel SC, Newport EL, and Aslin RN (2004) Distant melodies: Statistical learning of nonadjacent dependencies in tone sequences. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 1119–1130.

Curran T (1997) Higher-order associative learning in amnesia: Evidence from the serial reaction time task. *J. Cogn. Neurosci.* 9: 522–533.

Destrebecqz A and Cleeremans A (2001) Can sequence learning be implicit? New evidence with the process dissociation procedure. *Psychon. Bull. Rev.* 8: 343–350.

Destrebecqz A and Cleeremans A (2003) Temporal effects in sequence learning. In: Jimenez L (ed.) *Attention and Implicit Learning*, pp. 181–213. Amsterdam: John Benjamins.

Detable C and Vinter A (2004) The preservation in time of implicit learning effects in children and adolescents with mental retardation. *Annee Psychol.* 104: 751–770.

Dienes Z (1992) Connectionist and memory-array models of artificial grammar learning. *Cogn. Sci.* 16: 41–79.

Dienes Z and Altmann G (1997) Transfer of implicit knowledge across domains: How implicit and how abstract? In: Berry D (ed.) *How Implicit Is Implicit Learning?* pp. 107–123. Oxford: Oxford University Press.

Dienes Z, Altmann GTM, Kwan L, and Goode A (1995) Unconscious knowledge of artificial grammars is applied strategically. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 1322–1338.

Dienes Z, Broadbent D, and Berry D (1991) Implicit and explicit knowledge bases in artificial grammar learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 17: 875–887.

Dienes Z and Longuet-Higgins C (2004) Can musical transformations be implicitly learned? *Cogn. Sci.* 28: 531–558.

Don AJ, Schellenberg EG, Reber AS, DiGirolamo KM, and Wang PP (2003) Implicit learning in children and adults with Williams syndrome. *Dev. Neuropsychol.* 23: 201–225.

Dulany DE (1961) Hypotheses and habits in verbal ''operant conditioning''. *J. Abnorm. Soc. Psychol.* 63: 251–263.

Dulany DE, Carlson A, and Dewey GI (1984) A case of syntactical learning and judgment: How conscious and how abstract? *J. Exp. Psychol. Gen.* 113: 541–555.

Eldridge LL, Masterman D, and Knowlton BJ (2002) Intact implicit habit learning in Alzheimer's disease. *Behav. Neurosci.* 116: 722–726.

Ellis NC (*ed*.) (1994) *Implicit and Explicit Learning of Languages*. New York: Academic Press.

Elman JL (1990) Finding structure in time. *Cogn. Sci.* 14: 179–211.

Fillingham JK, Hodgson C, Sage K, and Lambon Ralph MA (2003) The application of errorless learning to aphasic disorders: A review of theory and practice. *Neuropsychol. Rehabil.* 13: 337–363.

Fiser J and Aslin RN (2001) Unsupervised statistical learning of higher-order spatial structures from visual scenes. *Psychol. Sci.* 12: 499–504.

Fiser J and Aslin RN (2002) Statistical learning of higher-order temporal structure from visual shape sequences. *J. Exp. Psychol. Learn. Mem. Cognit.* 28: 458–467.

Fiser J and Aslin RN (2005) Encoding multielement scenes: Statistical learning of visual features hierarchies. *J. Exp. Psychol. Gen.* 134: 521–537.

French RA and Cleeremans A (eds.) (2002) *Implicit Learning*, pp. 121–143. London: Routledge, Psychology Press.

Frensch PA (1998) One concept, multiple meanings. In: Stadler M and Frensch P (eds.) *Handbook of Implicit Learning*, pp. 47–104. Thousand Oaks, CA: Sage Publications.

Frensch PA, Buchner A, and Lin J (1994) Implicit learning of unique and ambiguous serial transitions in the presence and absence of a distractor task. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 567–584.

Gomez RL (1997) Transfer and complexity in artificial grammar learning. *Cogn. Psychol.* 33: 154–207.

Gomez R (2002) Variability and detection of invariant structure. *Psychol. Sci.* 13: 431–436.

Gomez RL and Gerken LA (1999) Artificial grammar learning by one-year-olds leads to specific and abstract knowledge. *Cognition* 70: 109–135.

Gomez RL and Gerken LA (2000) Infant artificial language learning and language acquisition. *Trends Cogn. Sci.* 4: 178–186.

Gomez RL, Gerken LA, and Schvaneveldt RW (2000) The basis of transfer in artificial grammar learning. *Mem. Cognit.* 28: 253–263.

Gomez RL and Schvanevelt RW (1994) What is learned from artificial grammar? Transfer tests of simple association. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 396–410.

Graham S (2000) Should the natural learning approach replace spelling instruction? *J. Educ. Psychol.* 92: 235–247.

Green REA and Shanks DR (1993) On the existence of independent learning systems: An examination of some evidence. *Mem. Cognit.* 21: 304–317.

Hauser MD, Newport EL, and Aslin RN (2001) Segmentation of the speech stream in a non-human primate: Statistical learning in cotton-top tamarins. *Cognition* 78: B53–B64.

Higham PA (1997) Dissociations of grammaticality and specific similarity effects in artificial grammar learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 23: 1029–1045.

Higham PA, Vokey JR, and Pritchard JL (2000) Beyond dissociation logic: Evidence for controlled and automatic influences in artificial grammar learning. *J. Exp. Psychol. Gen.* 129: 457–470.

Hoffmann J and Sebald A (2005) When obvious covariations are not even learned implicitly. *Eur. J. Cogn. Psychol.* 17: 449–480.

Howard DV, Howard JH, Jakipse K, DiYanni C, Thompson A, and Somberg R (2004) Implicit sequence learning: Effects of level of structure, adult age, and extended practice. *Psychol. Aging* 19: 79–92.

Hsiao AT and Reber A (1998) The role of attention in implicit sequence learning: Exploring the limits of the cognitive unconscious. In: Stadler M and Frensch P (eds.) *Handbook of Implicit Learning*, pp. 471–494. Thousand Oaks, CA: Sage Publications.

Hunt RH and Aslin RN (2001) Statistical learning in a serial reaction time task: Access to separable statistical cues by individual learners. *J. Exp. Psychol. Gen.* 130: 658–680.

Jacoby LL (1983) Perceptual enhancement: Persistent effects of an experience. *J. Exp. Psychol. Learn. Mem. Cogn.* 9: 21–38.

Jacoby LL (1991) A process dissociation framework: Separating automatic from intentional uses of memory. *J. Mem. Lang.* 30: 513–541.

Jimenez L (2003) *Attention and Implicit Learning*. Amsterdam: John Benjamins.

Jimenez L and Mendez C (1999) Which attention is needed for implicit sequence learning? *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 236–259.

Johnstone T and Shanks DR (1999) Two mechanisms in implicit artificial grammar learning? Comment on Meulemans and Van der Linden (1997) *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 524–531.

Karatekin C, Marcus DJ, and White T (2006) Oculomotor and manual indexes of incidental and intentional spatial sequence learning during middle childhood and adolescence. *J. Exp. Child Psychol.* 96: 107–130.

Kemp N and Bryant P (2003) Do beez buzz? Rule-based and frequency-based knowledge in learning to spell plural -s. *Child Dev.* 74: 63–74.

Kinder A and Assmann A (2000) Learning artificial grammars: No evidence for the acquisition of rules. *Mem. Cognit.* 28: 1321–1332.

Kinder A, Shanks DR, Cock J, and Tunney RJ (2003) Recollection, fluency, and the explicit/implicit distinction in artificial grammar learning. *J. Exp. Psychol. Gen.* 132: 551–565.

Knowlton BJ and Squire LR (1994) The information acquired during artificial grammar learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 79–91.

Knowlton BJ and Squire LR (1996) Artificial grammar learning depends on implicit acquisition of both abstract and exemplar-specific information. *J. Exp. Psychol. Learn. Mem. Cogn.* 22: 169–181.

Krashen S (1981) *Second Language Acquisition and Second Language Learning*. New York: Prentice-Hall international.

Kuhn G and Dienes Z (2005) Implicit learning of non-local musical rules. *J. Exp. Psychol. Learn. Mem. Cogn.* 31: 1417–1432.

Kunimoto C, Miller J, and Pashler H (2001) Confidence and accuracy of near-threshold discrimination responses. *Conscious. Cogn.* 10: 294–340.

Kushner M, Cleeremans A, and Reber A (1991) Implicit detection of event interdependencies, and a PDP model of the process. In: *Proceedings of the Thirteenth Annual Conference of the Cognitive Science Society: 7–10 August*

*1991, Chicago, Illinois*, pp. 215–221. Hillsdale, NJ: Lawrence Erlbaum Associates.
Lewicki P, Hill T, and Bizot E (1988) Acquisition of procedural knowledge about a pattern of stimuli that cannot be articulated. *Cognit. Psychol.* 20: 24–37.
Lewicki P, Hill T, and Czyzewska M (1992) Nonconscious acquisition of information. *Am. Psychol.* 47: 796–801.
Lotz A and Kinder A (2006) Transfer in artificial grammar learning: The role of repetition information. *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 707–715.
Manza L and Reber AS (1997) Representing artificial grammars: Transfer across stimulus forms and modalities. In: Berry DC (ed.) *How Implicit Is Implicit Learning?* pp. 73–106. Oxford: Oxford University Press.
Manza L, Zizak D, and Reber AS (1998) Artificial grammar learning and the Mere Exposure Effect: Emotional preference tasks and the implicit learning process. In: Stadler M and Frensch P (eds.) *Handbook of Implicit Learning*, pp. 201–222. Thousand Oaks, CA: Sage Publications.
Marcus GF, Vijayan S, Rao SB, and Vishton PM (1999) Rule learning by Seven-Month-Old Infants. *Science* 283: 77–80.
Mathews RC, Buss RR, Stanley WB, Blancard-Fields F, Cho J-R, and Druhan B (1989) Role of implicit and explicit processes in learning from examples: A synergistic effect. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 1083–1100.
McAndrews MP and Moscovitch M (1985) Rule-based and exemplar-based classification in artificial grammar learning. *Mem. Cognit.* 13: 468–475.
McClelland JL and Patterson K (2002) Rules or connections in past-tense inflections: What does the evidence rule out? *Trends Cogn. Sci.* 6: 465–472.
McClelland JL and Plaut DC (1999) Does generalization in infant learning implicate abstract algebra-like rules? *Trends Cogn. Sci.* 3: 166–168.
McGeorge P and Burton AM (1990) Semantic processing in an incidental learning task. *Q. J. Exp. Psychol.* 42A: 597–609.
Meier B and Perrig WJ (2000) Low reliability of perceptual priming: Consequences for the interpretation of functional dissociations between explicit and implicit memory. *Q. J. Exp. Psychol.* 53A: 211–233.
Meulemans T and Van der Linden M (1997) Chunk strength and artificial grammar learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 23: 1007–1028.
Meulemans T and Van der Linden M (2003) Implicit learning of complex information in amnesia. *Brain Cogn.* 52: 250–257.
Meulemans T, Van Der Linden M, and Perruchet P (1998) Implicit sequence learning in children. *J. Exp. Child Psychol.* 69: 199–221.
Monaghan P, Chater N, and Christiansen MH (2005) The differential role of phonological and distributional cues in grammatical categorisation. *Cognition* 96: 143–182.
Neal A and Hesketh B (1997) Episodic knowledge and implicit learning. *Psychon. Bull. Rev.* 4: 24–37.
Negash S, Howard DV, Japikse KC, and Howard JH, Jr. (2003) Age-related differences in implicit learning of non-spatial sequential patterns. *Aging Neuropsychol. Cognit.* 10: 108–121.
Newell BR and Bright JEH (2002) Well past midnight: Calling time on implicit invariant learning? *Eur. J. Cogn. Psychol.* 14: 185–205.
Newport EL and Aslin RN (2004) Learning at a distance: I. Statistical learning of non-adjacent dependencies. *Cognit. Psychol.* 48: 127–162.
Onnis L, Monaghan P, Chater N, and Richmond (2005) Phonology impacts segmentation in online speech processing. *J. Mem. Lang.* 53: 225–237.
Pacton S and Deacon H (in press) The timing and mechanism of children's use of morphological information in spelling: Evidence from English and French. *Cogn. Dev.*
Pacton S, Fayol M, and Perruchet P (2005) Children's implicit learning of Graphotactic and Morphological regularities in French. *Child Dev.* 76: 324–339.
Pacton S and Perruchet P (in press) An attention-based associative account of adjacent and nonadjacent dependency learning. *J. Exp. Psychol. Learn. Mem. Cogn.*
Pacton S, Perruchet P, Fayol M, and Cleeremans A (2001) Implicit learning out of the lab: The case of orthographic regularities. *J. Exp. Psychol. Gen.* 130: 401–426.
Perruchet P (1994a) Defining the knowledge units of a synthetic language: Comment on Vokey and Brooks (1992) *J. Exp. Psychol. Learn. Mem. Cog.* 20: 223–228.
Perruchet P (1994b) Learning from complex rule-governed environments: On the proper functions of nonconscious and conscious processes. In: Umilta C and Moscovitch M (eds.) *Attention and Performance XV: Conscious and Nonconscious Information Processing*, pp. 811–835. Cambridge, MA: MIT Press.
Perruchet P (2005) Statistical approaches to language acquisition and the self-organizing consciousness: A reversal of perspective. *Psychol. Res.* 69: 316–329.
Perruchet P and Amorim MA (1992) Conscious knowledge and changes in performance in sequence learning: Evidence against dissociation. *J. Exp. Psychol. Learn. Mem. Cog.* 18: 785–800.
Perruchet P, Gallego J, and Pacteau C (1992) A reinterpretation of some earlier evidence for abstractiveness of implicitly acquired knowledge. *Q. J. Exp. Psychol.* 44A: 193–210.
Perruchet P, Gallego J, and Savy I (1990) A critical reappraisal of the evidence for unconscious abstraction of deterministic rules in complex experimental situations. *Cognit. Psychol.* 22: 493–516.
Perruchet P and Pacteau C (1990) Synthetic grammar learning: Implicit rule abstraction or explicit fragmentary knowledge? *J. Exp. Psychol. Gen.* 119: 264–75.
Perruchet P and Pacton S (2006) Implicit learning and statistical learning: Two approaches, one phenomenon. *Trends Cogn. Sci.* 10: 233–238.
Perruchet P and Peereman R (2004) The exploitation of distributional information in syllable processing. *J. Neurolinguists.* 17: 97–119.
Perruchet P, Tyler MD, Galland N, and Peereman R (2004) Learning non-adjacent dependencies: No need for algebraic-like computations. *J. Exp. Psychol. Gen.* 133: 573–583.
Perruchet P and Vinter A (1998a) PARSER: A model for word segmentation. *J. Mem. Lang.* 39: 246–263.
Perruchet P and Vinter A (1998b) Learning and development: The implicit knowledge assumption reconsidered. In: Stadler M and Frensch P (eds.), *Handbook of Implicit Learning*, pp. 495–531. Thousand Oaks, CA: Sage Publications.
Perruchet P and Vinter A (2002) The self-organized consciousness. *Behav. Brain Sci.* 25: 297–388.
Perruchet P, Vinter A, and Gallego J (1997) Implicit learning shapes new conscious percepts and representations. *Psychon. Bull. Rev.* 4: 43–48.
Perruchet P, Vinter A, Pacteau C, and Gallego J (2002) The formation of structurally relevant units in artificial grammar learning. *Q. J. Exp. Psychol.* 55A: 485–503.
Pothos EM (2005) Expectations about stimulus structure in implicit learning. *Mem. Cognit.* 33: 171–181.
Pothos EM and Bailey TM (2000) The role of similarity in artificial grammar learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 847–862.
Reber AS (1967) Implicit learning of artificial grammars. *J. Verbal Learn. Verbal Behav.* 6: 855–863.
Reber AS (1969) Transfer of syntactic structure in synthetic languages. *J. Exp. Psychol.* 81: 115–119.
Reber AS (1989) Implicit learning and tacit knowledge. *J. Exp. Psychol. Gen.* 118: 219–35.

Reber AS (1993) *Implicit Learning and Tacit Knowledge: an Essay on the Cognitive Unconscious*. Oxford University Press, New York.
Reber AS and Allen R (1978) Analogy and abstraction strategies in synthetic grammar learning: A functionalist interpretation. *Cognition* 6: 189–221.
Reber P and Lewis S (1977) Toward a theory of implicit learning: The analysis of the form and structure of a body of tacit knowledge. *Cognition* 5: 333–361.
Redington M and Chater N (1998) Connectionist and statistical approaches to language acquisition: A distributional perspective. *Lang. Cogn. Processes* 13: 129–191.
Redington M and Chater N (2002) Knowledge representation and transfer in artificial grammar learning. In: French RA and Cleeremans A (eds.) *Implicit Learning*, pp. 121–143. London: Routledge, Psychology Press.
Redington M, Chater N, and Finch S (1998) Distributional information: A powerful cue for acquiring syntactic categories. *Cogn. Sci.* 22: 425–469.
Reed J and Johnson P (1994) Assessing implicit learning with indirect tests: Determining what is learned about sequence structure. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 585–594.
Remillard G and Clark JM (2001) Implicit learning of first-, second-, and third-order transition probabilities. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 483–498.
Rescorla RA (1967) Pavlovian conditioning and its proper control procedures. *Psychol. Rev.* 74: 71–80.
Robinson P (2002) Effects of individual differences in intelligence, aptitude and working memory on adult incidental SLA. In: Robinson P (ed.) *Individual Differences and Instructed Language Learning*, pp. 211–266. Amsterdam: John Benjamins.
Roediger HL, Weldon MS, and Challis BH (1989) Explaining dissociations between implicit and explicit measures of retention: A processing account. In: Roediger HL and Craik FIM (eds.) *Varieties of Memory and Consciousness: Essays in Honour of Endel Tulving*, pp. 3–39. Hillsdale, NJ: Erlbaum.
Rowland LA and Shanks DR (2006a) Sequence learning and selection difficulty. *J. Exp. Psychol. Hum. Percept. Perform.* 32: 287–299.
Rowland LA and Shanks DR (2006b) Attention modulates the learning of multiple contingencies. *Psychon. Bull. Rev.* 13: 643–648.
Saetrevik B, Reber R, and Saunnum P (2006) The utility of implicit learning in the teaching of rules. *Learn. Instruct.* 16: 363–373.
Saffran JR (2002) Constraints on statistical language learning. *J. Mem. Lang.* 47: 172–196.
Saffran JR, Aslin RN, and Newport EL (1996) Statistical learning by 8-month-old infants. *Science* 274: 1926–1928.
Saffran JR, Johnson EK, Aslin RN, and Newport EL (1999) Statistical learning of tone sequences by human infants and adults. *Cognition* 70: 27–52.
Saffran JR, Newport EL, Aslin RN, Tunick RA, and Barrueco S (1997) Incidental language learning. *Psychol. Sci.* 8: 101–105.
Saffran JR and Wilson DP (2003) From syllables to syntax: Multilevel statistical learning by 12-month-old infants. *Infancy* 4: 273–284.
Schwartz BL, Howard DV, Howard JH, Hovaguimian A, and Deutsch SI (2003) Implicit learning of visuospatial sequences in schizophrenia. *Neuropsychology* 17: 517–533.
Seger CA (1994) Implicit learning. *Psychol. Bull.* 115: 163–196.
Seidenberg MS and Elman JL (1999) Do infants learn grammar with algebra or statistics? *Science* 284: 433.
Servan-Schreiber D and Anderson JR (1990) Learning artificial grammars with competitive chunking. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 592–608.
Shanks DR (1995) *The Psychology of Associative Learning*. Cambridge: Cambridge University Press.
Shanks DR (2005) Implicit learning. In: Lamberts K and Goldstone R (eds.) *Handbook of Cognition*, pp. 202–220. London: Sage.
Shanks DR, Channon S, Wilkinson L, and Curran HV (2006) Disruption of sequential priming in organic and pharmacological amnesia: A role for the medial temporal lobes in implicit contextual learning. *Neuropsychopharmacology* 31: 1768–1776.
Shanks DR and Johnstone T (1999) Evaluating the relationship between explicit and implicit knowledge in a sequential reaction time task. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 1435–1451.
Shanks DR, Johnstone T, and Staggs L (1997) Abstraction processes in artificial grammar learning. *Q. J. Exp. Psychol.* 50A: 216–252.
Shanks DR and Perruchet P (2002) Dissociation between priming and recognition in the expression of sequential knowledge. *Psychon. Bull. Rev.* 9: 362–367.
Shanks DR and St. John MF (1994) Characteristics of dissociable human learning systems. *Behav. Brain Sci.* 17: 367–447.
Shanks DR, Wilkinson L, and Channon S (2003) Relationship between priming and recognition in deterministic and probabilistic sequence learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 248–261.
Shanks DR and St. John MF (1994) Characteristics of dissociable human learning systems. *Behav. Brain Sci.* 17: 367–447.
Shukla M, Nespor M, and Mehler J (2007) An interaction between prosody and statistics in the segmentation of fluent speech. *Cognit. Psychol.* 54: 1–32.
Smith EE, Langston C, and Nisbett RE (1992) The case for rules in reasoning. *Cogn. Sci.* 16: 1–40.
Smith JG and McDowall J (2006) When artificial grammar acquisition in Parkinson's disease is impaired: The case of learning via trial-by-trial feedback. *Brain Res.* 1067: 216–228.
Stadler MA (1989) On learning complex procedural knowledge. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 1061–1069.
Stadler MA (1995) Role of attention in implicit learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 674–685.
Stadler MA and Frensch P (1994) Whither learning, whither memory? *Behav. Brain Sci.* 17: 423–424.
Stadler MA and Frensch P (1998) *Handbook of Implicit Learning*. Thousand Oaks, CA: Sage Publications.
Thiessen ED and Saffran JR (2003) When cues collide: Use of stress and statistical cues to word boundaries by 7- to 9-month-old infants. *Dev. Psychol.* 39: 706–716.
Toro JM, Sinnett S, and Soto-Faraco S (2005) Speech segmentation by statistical learning depends on attention. *Cognition* 97: B25–B34.
Toro JM and Trobalon JB (2005) Statistical computation over a speech stream in a rodent. *Percept. Psychophys.* 67: 867–875.
Tunney RJ and Altmann GTM (1999) The transfer effect in artificial grammar learning: Re-appraising the evidence of transfer of sequential dependencies. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 1322–1333.
Tunney RJ and Shanks DR (2003a) Does opposition logic provide evidence for conscious and unconscious processes in artificial grammar learning? *Conscious. Cogn.* 12: 201–218.
Tunney RJ and Shanks DR (2003b) Subjective measures of awareness and implicit cognition. *Mem. Cognit.* 31: 1060–1071.
Turk-Browne NB, Jungé J, and Scholl BJ (2005) The automaticity of visual statistical learning. *J. Exp. Psychol. Gen.* 134: 552–564.
Turner CW and Fischler IS (1993) Speeded test of implicit knowledge. *J. Exp. Psychol. Learn. Mem. Cogn.* 19: 1165–1177.

Tzelgov J, Henik A, and Berger J (1992) Controlling Stroop effects by manipulating expectations for color words. *Mem. Cognit.* 20: 727–735.

Vakil E, Kraus A, Bor B, and Groswasser Z (2002) Impaired skill learning in patients with severe closed-head injury as demonstrated by the serial reaction time (SRT) task. *Brain Cogn.* 50: 304–315.

Vinter A and Detable C (2003) Implicit learning in children and adolescent mental retardation. *Amer. J. Ment. Retard.* 108: 94–107.

Vinter A and Perruchet P (2000) Implicit learning in children is not related to age : Evidence from drawing behavior. *Child Dev.* 71: 1223–1240.

Vokey JR and Brooks LR (1992) Salience of item knowledgein learning artificial grammar. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 328–344.

Whittlesea BWA and Dorken MD (1993) Incidentally, things in general are incidentally determined: An episodic-processing account of implicit learning. *J. Exp. Psychol. Gen.* 122: 227–248.

Whittlesea BWA and Dorken MD (1997) Implicit learning: Indirect, not unconscious. *Psychon. Bull. Rev.* 4: 63–67.

Whittlesea BW and Williams LD (2000) The discrepancy-attribution hypothesis: II Expectation, uncertainty, surprise, and feelings of familiarity. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 14–33.

Whittlesea BWA and Wright RL (1997) Implicit (and explicit) learning: Acting adaptively without knowing the consequences. *J. Exp. Psychol. Learn. Mem. Cogn.* 23: 181–200.

Wilkinson L and Shanks DR (2004) Intentional control and implicit sequence learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 354–369.

Willingham DB, Greeley T, and Bardone AM (1993) Dissociation in a serial response time task using a recognition measure: Comment on Perruchet and Amorim (1992). *J. Exp. Psychol. Learn. Mem. Cogn.* 19: 1424–1430.

Willingham DB, Nissen MJ, and Bullemer P (1989) On the development of procedural knowledge. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 1047–1060.

Wright RL and Burton AM (1995) Implicit learning of an invariant: Just say no. *Q. J. Exp. Psychol.* 48A: 783–796.

Zizak DM and Reber AR (2004) Implicit preferences: The role(s) of familiarity in the structural mere exposure effect. *Conscious. Cogn.* 13: 336–362.

# 2.33 Implicit Memory and Priming

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## 2.33.1 Introduction

Priming refers to an improvement or change in the identification, production, or classification of a stimulus as a result of a prior encounter with the same or a related stimulus (Tulving and Schacter, 1990). Cognitive and neuropsychological evidence indicates that priming reflects the operation of implicit or nonconscious processes that can be dissociated from those that support explicit or conscious recollection of past experiences. More recently, neuroimaging studies have revealed that priming is often accompanied by decreased activity in a variety of brain regions (for review, see Schacter and Buckner, 1998; Wiggs and Martin, 1998; Henson, 2003), although conditions exist in which priming-related increases are also observed (e.g., Schacter et al., 1995; Henson et al., 2000; Fiebach et al., 2005). Various terms have been used to describe these neural changes, including adaptation, mnemonic filtering, repetition suppression, and repetition enhancement. These terms often refer to subtly distinct, though related, phenomena, and in some cases belie a theoretical bias as to the nature of such neural changes. Thus, throughout the present review, the term neural priming will be used to refer to changes in neural activity associated with the processing of a stimulus that result from a previous encounter with the same or a related stimulus.

When considering the link between behavioral and neural priming, it is important to acknowledge that functional neuroimaging relies on a number of underlying assumptions. First, changes in information processing result in changes in neural activity within brain regions subserving these processing operations. A second assumption underlying positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) is that these changes in neural activity are accompanied by changes in blood flow, such that the energy expenditure that accompanies increased neuronal processing elicits the delivery of metabolites and removal of by-products to and from active regions, respectively. It is these local vascular changes that are measured: PET measures changes in cerebral blood flow and oxygen or glucose utilization, while fMRI measures the ratio of oxygenated to deoxygenated hemoglobin (i.e., the blood-oxygen-level dependent, or BOLD, signal). Related techniques such as event-related potentials (ERP) and magnetoencephalography (MEG), by contrast, measure the electrophysiological responses of neural populations more directly, although at a cost of decreased spatial resolution. While this chapter will focus on fMRI and to a lesser extent PET studies of priming, ERP and MEG studies will be discussed when they are of special interest to the discussion of a particular topic.

Neuroimaging studies have provided new means of addressing cognitive theories that have traditionally been evaluated through behavioral studies. The primary goal of the present chapter is to examine how neuroimaging evidence has informed, influenced, and reshaped cognitive theories about the nature of priming. We focus on five research areas where such interaction has occurred: influences of explicit versus implicit memory, top-down attentional effects, specificity of priming, the nature of priming-related activation increases, and correlations between brain activity and behavior.

## 2.33.2 Influences of Explicit Versus Implicit Memory

Priming is typically defined as a nonconscious or implicit form of memory. This characterization is supported by numerous observations of spared priming in amnesic patients with severe disorders of explicit memory. However, starting with the earliest cognitive studies of priming in healthy volunteers, researchers have been concerned with the possibility that subjects may use some type of explicit retrieval to perform a nominally implicit task. This concern has led to the development of various cognitive procedures for estimating and removing the influences of explicit retrieval (e.g., Schacter et al., 1989; Jacoby, 1991). Two forms of such explicit 'contamination' have received attention in cognitive studies: (1) subjects realize that their memory is being tested, and intentionally retrieve study list words while performing a priming task to augment performance; (2) subjects follow task instructions, and therefore do not engage in intentional retrieval, but nonetheless unintentionally recollect that they had studied target items on the previous study list. With respect to the latter type of contamination, it has been noted that explicit memory often takes the form of unintentional or involuntary recollections of previous experiences in which there is no deliberate, effortful attempt to think back to the past; one is spontaneously 'reminded' of a past event that is accompanied by conscious recollection (e.g., Schacter, 1987; Schacter et al., 1989; Richardson-Klavehn et al., 1994; Richardson-Klavehn and Gardiner, 1998; Bernsten and Hall, 2004). We now consider findings from neuroimaging studies that provide insights into the nature of and relation between implicit and explicit influences on priming.

The explicit contamination issue arose in the first neuroimaging study of priming (Squire et al., 1992). In this experiment, subjects semantically encoded a list of familiar words prior to PET scanning and were then scanned during a stem completion task in which they provided the first word that came to mind in response to visual three-letter word stems. During one scan, subjects could complete stems with study list words (priming), and during another, they could complete stems only with new words that had not been presented on the study list (baseline). In a separate scan, subjects were provided with three-letter stems of study-list words, and were asked to think back to the study list (explicit cued recall).

Priming was associated with decreased activity in the right extrastriate occipital cortex compared with baseline, but there was also increased activity in the right hippocampal formation during priming compared with the baseline condition. In light of previous results from amnesic patients indicating that normal stem-completion priming can occur even when the hippocampal formation is damaged, it seemed likely that the observed activation of the hippocampal region reflects one of the two previously mentioned forms of 'contamination': subjects intentionally retrieved words from the study list or, alternatively, they provided the first word that comes to mind and involuntarily recollected its prior occurrence.

Schacter et al. (1996) attempted to reduce or eliminate explicit influences by using a nonsemantic study task (counting the number of t-junctions in each of target words), which in previous behavioral studies had supported robust stem-completion priming together with poor explicit memory for the target items (e.g., Graf and Mandler, 1984; Bowers and Schacter, 1990). Consistent with the idea that the priming-related hippocampal activation previously observed by Squire et al. reflects contamination from explicit memory that is not essential to observing priming, following the t-junction encoding task there was no evidence of priming-related increases in the vicinity of the hippocampal formation during stem completion performance relative to the baseline task, but there were priming-related decreases in bilateral extrastriate occipital cortex and several other regions.

Using PET, Rugg et al. (1997) found greater left hippocampal activity after deep encoding than after shallow encoding during both intentional (old/new recognition) and unintentional (animate/inanimate decision) retrieval tasks. They also observed greater right anterior prefrontal activity during intentional retrieval than during unintentional retrieval after both deep and shallow encoding. These results suggest that increases in hippocampal activity during explicit retrieval, unaccompanied by corresponding increases in anterior prefrontal activity, reflect the presence of involuntary explicit memory.

A more recent event-related fMRI study by Schott et al. (2005) extends the findings of these early studies. During the study phase, subjects made nonsemantic encoding judgments in which they counted the number of syllables in each word. During the test phase, Schott et al. used a stem completion task and directly compared performance during intentional retrieval (i.e., try to remember a word from the list beginning with these three letters) and incidental retrieval (i.e., complete the stem with the first word that comes to mind). Importantly, they used a behavioral procedure developed by Richardson-Klavehn and Gardiner (1996, 1998) in which participants indicate whether or not they remember that the item they produced on the completion task had appeared earlier during the study task. This procedure could be applied to both the incidental and intentional tests, because on the intentional test subjects were told to complete stems even when they could not recall a study-list item. In the scanner, subjects used a button press to indicate whether they had covertly completed a stem; between these test trials, they provided their completions orally and indicated whether or not they remembered having seen the item during the study task. Stems completed with study-list words that were judged as nonstudied were classified as primed items, whereas stems completed with study-list words judged as studied were classified as remembered items. Both primed and remembered items were compared with baseline items that subjects judged correctly as nonstudied.

Similar to previous studies, Schott et al. (2005) documented activation reductions for primed items compared with baseline items in a number of regions, including extrastriate visual cortex. However, because the primed items in this study were, by definition, ones that subjects did not consciously remember having encountered previously, these data show more convincingly than earlier studies that priming-related activation decreases can reflect strictly nonconscious or implicit memory. Moreover, the authors also reported that their findings concerning priming-related reductions during the incidental tests were largely replicated during the intentional test. Thus, the results support the idea that priming effects can occur during both intentional and unintentional retrieval. Several other regions, including the right prefrontal cortex, showed greater activity during the intentional than the incidental task. In contrast to prior studies, the hippocampus showed greater activity during baseline than during priming, which the authors attributed to novelty encoding. Overall, these neuroimaging results support earlier behavioral distinctions between strategic controlled retrieval (i.e., intentional vs. incidental) and conscious recollection of the occurrence of previously studied items and show clearly that priming-accompanied activation reductions can occur without conscious recollection.

While the foregoing studies attempted to distinguish implicit and explicit aspects of priming by focusing on retrieval, other studies have done so by examining brain activity during encoding. Schott et al. (2006) examined subsequent memory effects, where neural activity during encoding is sorted according to whether items are subsequently remembered or forgotten (e.g., Brewer et al., 1998; Wagner et al., 1998). This study reported fMRI data from the encoding phase of the aforementioned stem completion experiment reported by Schott et al. (2005), where participants counted the number of syllables in each word. Consistent with results from earlier subsequent memory studies that examined explicit retrieval, Schott et al. found greater activation during encoding for subsequently remembered than for forgotten items in left inferior prefrontal cortex and bilateral medial temporal lobe. By contrast, encoding activity in these areas was not associated with subsequently primed items. Instead, subsequent priming was associated with activation decreases during encoding in bilateral extrastriate cortex, left fusiform gyrus, and bilateral inferior frontal gyrus. These regions were distinct from those that showed priming-related decreases during the stem completion test. Schott et al. suggest that their data indicate that priming, in contrast to explicit memory, is associated with sharpening of perceptual representations during encoding, an idea that is consistent with previous theories emphasizing the differential role of a perceptual representation system in priming and explicit memory (Schacter, 1990, 1994; Tulving and Schacter, 1990).

While the combined results from Schott et al.'s (2005, 2006) encoding and retrieval phases highlight clear differences between priming and explicit memory, a related study by Turk-Browne et al. (2006), also using a subsequent memory paradigm, uncovered conditions under which the two forms of memory are associated with one another. Subjects made indoor/outdoor decisions about a series of novel scenes. Each scene was repeated once, at lags ranging from 2 to 11 items. Fifteen minutes after presentation of the final scene, subjects were given a surprise old/new recognition test. Turk-Browne et al. focused on a region of interest in the parahippocampal place area (PPA) that responds maximally to visual scenes (e.g., Epstein and Kanwisher, 1998). The critical outcome was that repeated scenes produced behavioral priming and reduced activation in the PPA, but only for those scenes that were subsequently remembered. Forgotten items did not produce either behavioral or neural priming. A whole-brain analysis revealed similar effects – neural priming for remembered items only – in bilateral PPA as well as in left inferior temporal gyrus and bilateral angular gyrus. However, forgotten items were associated with neural priming in the anterior cingulate.

Given the general trend that behavioral and neural priming both depended on subsequent explicit memory, Turk-Browne et al. suggested that their data reveal a link between implicit and explicit memory that involves some aspect of shared encoding processes – most likely that selective attention during encoding is required for both subsequent priming and explicit memory.

The neuroimaging evidence considered thus far reveals some conditions under which priming can occur independently of explicit memory and others where dependence exists. An experiment by Wagner et al. (2000) showed that priming can sometimes hinder explicit memory. They made use of the well-known spacing or lag effect, where reencoding an item after a short lag following its initial presentation typically produces lower levels of subsequent explicit memory than reencoding an item after a long lag (though in both cases, explicit memory is higher than with no repetition). Using an incidental encoding task (abstract/concrete judgment) and old/new recognition task, Wagner et al. documented greater explicit memory following a long- than a short-lag condition, consistent with previous behavioral findings. By contrast, they showed greater behavioral priming, indexed by reduced reaction time, and greater neural priming, indexed by reduced activity in the left inferior frontal lobe, following a short lag than a long lag. Moreover, there was a negative correlation between the magnitude of neural priming in the left inferior frontal region and the level of subsequent explicit memory. Thus, the short-lag condition that maximized priming also reduced explicit memory. Although the exact mechanism underlying the effect is still not known, Wagner et al. suggested that priming may impair new episodic encoding and later explicit memory by reducing encoding variability, that is, encoding different attributes of repeated items on different trials. To the extent that encoding variability normally enhances subsequent memory by providing multiple retrieval routes to an item (e.g., Martin, 1968), priming might reduce explicit memory because it biases encoding toward sampling the same item features on multiple trials. Whatever the ultimate explanation, these results highlight the role of a previously unsuspected interaction between priming and explicit memory in producing a well-known behavioral effect.

## 2.33.3 Top-Down Attentional Effects on Priming

Priming is often considered to be an automatic process (e.g., Jacoby and Dallas, 1981; Tulving and Schacter, 1990; Wiggs and Martin, 1998). However, recent neuroimaging evidence has revealed that, to some extent, behavioral and neural priming may be affected by top-down cognitive processes such as attention or task orientation.

### 2.33.3.1 Priming: Automatic/Independent of Attention?

Early evidence supported the notion that perceptual priming effects occur independent of manipulations of attention (for review see Mulligan and Hartman, 1996). However, subsequent findings from behavioral studies began to reveal that some perceptual priming effects do depend to some degree on attention at study (e.g., Mulligan and Hornstein, 2000).

In a seminal review that linked behavioral priming with the phenomenon of repetition suppression, Wiggs and Martin (1998) stated that this process "happens automatically in the cortex" and "is an intrinsic property of cortical neurons," and that "perceptual priming is impervious to . . . attentional manipulations" (Wiggs and Martin, 1998: 231). Indeed, there is some compelling evidence from studies with monkeys to suggest that repetition-related neural priming can occur independent of attention (e.g., Miller et al., 1991; Miller and Desimone, 1993; Vogels et al., 1995), but these findings do not speak directly to neural priming in humans. Some neuroimaging evidence shows that conditions exist under which both behavioral and neural priming are unaffected by manipulations of attention. A PET study by Badgaiyan et al. (2001) investigated the effects of an attentional manipulation during the study phase of a cross-modal priming task. Target words were aurally presented among distracter words at study under either full attention or under a divided-attention task. At test, visual word stems were presented in separate blocks for both target word types. Behavioral priming (faster reaction times) and neural priming (reduced regional cerebral blood flow in superior temporal gyrus) were of similar magnitude for words presented under full and divided attention conditions (see also Voss and Paller, 2006).

An fMRI study that we reviewed earlier (Schott et al., 2005) further demonstrated that changing the nature of the task to be performed during the test phase did not affect the level of behavioral or neural priming. Following shallow encoding of words at study, word stems were presented in separate blocks of either an implicit or an explicit memory task at test. Although the explicit task elicited a higher rate of explicit recollection of previously studied words, there were no differences in behavioral priming effects between the two conditions – i.e., subjects produced an equivalent number of previously studied words when cued with word stems in both test conditions. Moreover, an equivalent degree of neural priming was documented in left fusiform, bilateral frontal, and occipital brain regions in both implicit and explicit conditions. Thus, this experiment demonstrated that changing the task orientation at test had no effect on behavioral or neural priming.

Hasson et al. (2006) demonstrated comparable neural priming in some brain regions despite a change of task orientation across separate sessions (i.e., separate experiments with different tasks). In the first of two experiments, subjects listened to spoken sentences, some grammatically sensible, some nonsensible, and decided whether each sentence was sensible or not. In the second experiment, subjects passively listened to spoken sensible sentences only, making no judgments or responses. A direct contrast between the two tasks indicated that neural priming in temporal regions was equivalent across conditions. However, neural priming was also observed in inferior frontal regions, but only in the active condition in which subjects made sensible/nonsensible judgments. This finding suggests that attentional manipulations have variable effects on different brain regions.

The foregoing studies have demonstrated that behavioral and/or neural priming can occur independent of shifts in attentional demands or task orientation at study (Badgaiyan et al., 2001; Voss and Paller, 2006), at test (Schott et al., 2005), or between different tasks (Hasson et al., 2006). However, consistent with the latter finding by Hasson et al. of concurrent attenuation of priming in prefrontal regions associated with changing task demands, these null results do not rule out the possibility that under different task conditions, and in different brain regions, top-down attentional effects may play an important role in priming. We consider now (and also later in the chapter) recent evidence that supports this claim.

### 2.33.3.2 Priming: Modulated by Attention

Henson et al. (2002) reported one of the first neuroimaging studies to demonstrate that neural priming is modulated by top-down cognitive factors. Subjects viewed pictures of famous and nonfamous faces, each presented twice at random intervals within one of two separate, consecutive task sessions. During the implicit task session, subjects performed a continuous famous/nonfamous face discrimination task; during the explicit task session, subjects performed a continuous new/old face recognition task. Neural priming was observed in a face-responsive region in the right fusiform gyrus for repeated famous faces only, consistent with previous findings (Henson et al., 2000), as well as for both famous and nonfamous faces in a left inferior occipital region. Neural priming in these regions occurred only in the implicit task. As stimuli were identical across the different task conditions, the modulation of neural priming was attributed to top-down effects of task orientation.

Although there were effects of attention on neural priming, behavioral priming seemed to be unaffected by top-down factors. Rather, behavioral priming, as indexed by reduced reaction time to respond to repeated presentations of famous faces relative to initial presentations, was equivalent in the implicit and explicit tasks. This result implies a dissociation between behavioral priming and neural priming observed in these brain regions. Further, attentional modulation varied only between sessions, i.e., the same task was performed on each stimulus during the initial and repeated presentations, leaving open the question of whether attentional factors exert an influence at study, at test, or on both occasions.

A subsequent fMRI study tested the hypothesis that attentional factors, specifically at study, have an impact on neural priming (Eger et al., 2004). During fMRI scanning, subjects performed a task at study in which two objects were simultaneously presented, one to the left and one to the right of a central fixation point. Importantly, subjects were cued to attend to either the left or right of center by a visual cue presented onscreen 100 ms prior to presentation of the 'prime' stimuli. A single 'probe' stimulus was subsequently presented in the center of the screen that matched the previously attended stimulus, matched the previously unattended stimulus, was the mirror image of one of these two stimuli, or was novel. Analyses of repetition-related behavioral facilitation (faster reaction times) and neural response reductions (fMRI BOLD signal decreases in fusiform and lateral occipital regions) revealed that behavioral and neural priming occurred only for probes that matched (or mirrored) the attended prime. Conversely, no behavioral or neural priming was documented when the probe stimulus matched (or mirrored) the unattended prime. Thus, this study showed that modulation of spatial attention affects behavioral as well as neural priming in object selective perceptual processing regions, and that these top-down attentional effects exert an influence specifically at the time of study.

In a face-repetition priming study, Ishai et al. (2004) reported that neural priming occurred only for repeated faces that were task relevant. Subjects were presented with a target face and then were shown a series of faces, including three repetitions of the target face, three repetitions of a nontarget face, and seven distracter faces. Participants were required to push a button each time the target face appeared, and thus were required to attend to all faces, although only the target face was task relevant. Significant neural priming (reduced BOLD response for the third relative to the first repetition) was observed in face-responsive regions, including inferior occipital gyri, lateral fusiform gyri, superior temporal sulci, and amygdala, but only for the target face repetitions; no neural priming was associated with repetition of nontarget faces.

Yi and colleagues (Yi and Chun, 2005; Yi et al., 2006) used overlapping scene and face images to also demonstrate that task-relevant attention has an effect even for simultaneously viewed stimuli. In one experiment, participants were presented with overlapping face and scene images and instructed to attend only to the face or the scene on a given trial (Yi et al., 2006). Neural priming in a face-responsive fusiform region was documented only for repeated faces that were attended, and not for scenes or unattended faces. Similarly, neural priming in a scene-responsive parahippocampal region occurred only for repeated scenes that were attended, and not for faces or unattended scenes. Surprisingly, even after sixteen repetitions of a stimulus every 2 s within a block, no trace of neural priming was observed for unattended stimuli in these respective regions (Yi et al., 2006).

Thus, while a number of neuroimaging studies have shown that both behavioral and neural priming can remain constant across study and test manipulations of attention or between different tasks with common stimuli, several studies reviewed here indicate that top-down effects of attention can have an impact on behavioral and/or neural priming, both at the time of study (Henson et al., 2002) and at test (Ishai et al., 2004), and have been shown to involve both spatial attention (Eger et al., 2004) and task-relevant selective attention (Ishai et al., 2004; Yi and Chun, 2005; Yi et al., 2006). To reconcile these ostensibly incongruent conclusions requires a more detailed consideration of the nature of subtle differences in various manipulations of attention, and importantly, of the particular brain regions involved.

Accordingly, recent studies (e.g., Hassan et al., 2006) have begun to dissociate various brain regions that are differentially sensitive to various attentional manipulations. In a study by Vuilleumier et al. (2005), participants viewed overlapping objects drawn in two different colors at study and were instructed to attend only to objects of a specified color. At test, these objects were presented singly among novel real and nonsense objects, and subjects indicated whether each object was a real or nonsense object. Behavioral priming was documented both for previously attended and ignored objects, with a relative boost in performance for objects that were attended. However, different brain regions showed differential sensitivity to the effects of attention on neural priming. A group of regions that comprised right posterior fusiform, lateral occipital, and left inferior frontal regions demonstrated neural priming only for attended objects presented in the original view. By contrast, bilateral anterior fusiform regions were insensitive to changes of viewpoint (original vs.

mirrored), but showed neural priming for unattended objects in addition to more robust neural priming for attended objects. Finally, neural priming in the striate cortex was view specific and more robust for attended than ignored objects.

In keeping with the latter findings, O'Kane et al. (2005) reported a similar dissociation between brain regions differentially sensitive to manipulation of top-down processes. Subjects were presented with words at study and performed a judgment of either size, shape, or composition in separate task blocks. At test, subjects performed a size judgment for all studied words presented among novel words. Behavioral facilitation, as measured by faster reaction times for size judgments at test, was observed for repeated relative to novel words, with an additional benefit when the judgment was the same at study and test (size/size) relative to when the judgment was switched (shape/size or composition/size). Neural priming in left parahippocampal cortex tracked the behavioral trend, showing reduced BOLD responses for repeated relative to novel words, with an additional trend toward increased priming when the task was the same across repetition. In left perirhinal cortex, however, neural priming occurred for repeated words only when the judgment was the same at study and test. The finding that perirhinal cortex is sensitive to semantic but not perceptual repetition provides evidence that this region is involved in conceptual processing.

Considered together, the neuroimaging studies reviewed here suggest that behavioral and neural priming are indeed modulated by top-down cognitive factors of attention or task orientation, but that this modulation exerts differential effects across different brain regions depending on the nature of the task. Neural priming within a given brain region may occur only to the extent that the processing of a stimulus reengages this region in a qualitatively similar manner across repetitions.

### 2.33.3.3 Neural Mechanisms of Top-Down Attentional Modulation

Although the effects of attention on priming have now been well documented, little is known about the neural mechanisms that underlie these top-down effects. Efforts to understand these mechanisms have been at the forefront of recently emerging neuroimaging research.

Increased attention at the time of study has been suggested as an important factor in priming. Turk-Browne et al. (2006), as previously reviewed in this chapter, reported that neural priming occurred only for repeated scenes that were later remembered, but not for those scenes that were later forgotten. They found that tonic activation, a general measure of regional neural activity, was elevated for scenes that were later remembered and that also elicited neural priming upon repeated presentation. While previous evidence indicates that increased attention results in increased neural firing rates within process-relevant brain regions, a recent fMRI study suggests that attention may also increase selectivity of the neural population representing an attended stimulus (Murray and Wojciulik, 2004).

Other neuroimaging approaches, including MEG and EEG, have been used to further characterize the nature of attentional modulations of neural priming as well. Evidence supporting the hypothesis that attention serves to increase specificity of perceptual representations was reported by Duzel and colleagues (2005) in a study using MEG. By investigating neural activity at study, they compared words that showed subsequent behavioral priming (faster reaction times) to those that did not show subsequent priming. They reported relatively decreased amplitude, but increased phase alignment, of beta and gamma oscillations for words that showed later priming, indicating increased specificity of the neural response for these words at the time of study. Further, they reported increased coordination of activity between perceptual and higher brain regions for words that showed subsequent priming, as measured by increased interareal phase synchrony of alpha oscillations. Importantly, this increased synchrony between perceptual and higher brain regions was detected immediately prior to the initial presentation of the subsequently primed stimuli, indicating an anticipatory effect. These results suggest that top-down processes, through anticipatory coordination with perceptual brain regions, increase specificity of perceptual representations at study. Such a process may also be necessary at test for successful priming. Gruber et al. (2006) reported that 'sharpening' of the neural response in cell assemblies (as measured by suppression of induced gamma band responses in ERPs) occurred for repeated visual stimuli only when the task was the same at both study and test, but not when the task was switched.

Therefore, through a combination of various neuroimaging techniques, researchers have begun to characterize the neural mechanisms that underlie attentional modulation of priming. These mechanisms may constitute a link between the cognitive functions that are accessible to our conscious awareness and under our volitional control and the unconscious systems that facilitate fluency of mental processing.

## 2.33.4 Specificity of Priming

Priming effects vary in their specificity, that is, the degree to which priming is disrupted by changes between the encoding and test phases of an experiment. When study/test changes along a particular dimension produce a reduction in priming, the inference is that the observed priming effect is based to some extent on retention of the specific information that was changed; when level of priming is unaffected by a study/test change, the inference is that priming reflects the influence of an abstract representation, at least with respect to the changed attribute. Questions concerning the specificity of priming have been prominent since the early days of priming research in cognitive psychology, when evidence emerged that some priming effects are reduced when study/test sensory modality is changed (e.g., Jacoby and Dallas, 1981; Clarke and Morton, 1983) and can also exhibit within-modality perceptual specificity, shown by the effects of changing typeface or case for visual words (e.g., Roediger and Blaxton, 1987; Graf and Ryan, 1990), or speaker's voice for auditory words (e.g., Schacter and Church, 1992). Considerable theoretical debate has focused on the key issue raised by studies of specificity effects, namely whether priming reflects the influence of nonspecific, abstract preexisting representations or specific representations that reflect perceptual details of an encoding episode (for review and discussion of cognitive studies, see Roediger, 1990; Schacter, 1990, 1994; Roediger and McDermott, 1993; Tenpenny, 1995; Bowers, 2000).

Considering the early cognitive research together with more recent neuropsychological and neuroimaging studies, Schacter et al. (2004) recently proposed a distinction among three types of specificity effects: stimulus, associative, and response. Stimulus specificity occurs when priming is reduced by changing physical properties of a stimulus between study and test; associative specificity occurs when priming is reduced because associations between target items are changed between study and test; and response specificity occurs when priming is reduced because subjects make different responses to the same stimulus item at study and test. We will review here evidence from neuroimaging studies concerning each of the three types of priming specificity and consider how the imaging data bear on the kinds of theoretical questions that have been of interest to cognitive psychologists.

### 2.33.4.1 Stimulus Specificity

Most neuroimaging research has focused on stimulus specificity, which is observed by changing physical features of a stimulus between study and test. As mentioned earlier, cognitive studies have shown that priming effects are sometimes modality specific, that is, reduced when study and test sensory modalities are different compared with when they are the same. Such effects are most commonly observed on tasks such as word or object identification, stem completion, or fragment completion, which require perceptual or data-driven processing (Roediger and Blaxton, 1987). Amnesic patients have shown a normal modality-specific effect in stem completion priming (e.g., Carlesimo, 1994; Graf et al., 1985), suggesting that this effect is not dependent on the medial temporal lobe structures that are typically damaged in amnesics.

Early neuroimaging studies of within-modality visual priming that compared brain activity during primed and unprimed stem completion showed that priming is associated with decreased activity in various posterior and prefrontal cortical regions, but the decreases were observed most consistently in the right occipitotemporal extrastriate cortex (e.g., Squire et al., 1992; Buckner et al., 1995; Schacter et al., 1996). These and related findings raised the possibility that priming-related reductions in extrastriate activity are based on a modality-specific visual representation, perhaps reflecting tuning or sharpening of primed visual word representations (Wiggs and Martin, 1998). Consistent with this possibility, Schacter et al. (1999) directly compared within-modality visual priming to a cross-modality priming condition in which subjects heard words before receiving a visual stem completion task. They found priming-related reductions in extrastriate activity during within- but not cross-modality priming. Surprisingly, however, other neuroimaging studies of within-modality auditory stem completion priming also revealed priming-related activity reductions near the extrastriate region that was previously implicated in visual priming (Badgaiyan et al., 1999; Buckner et al., 2000; Carlesimo et al., 2004). These results remain poorly understood, but it has been suggested that one part of the extrastriate region (V3A, within BA 19) is involved in multimodal functions, perhaps converting perceptual information from one modality to another (Badgaiyan et al., 1999).

Although the results of imaging studies comparing within- and cross-modality priming are not entirely conclusive, studies of within-modality changes in physical properties of target stimuli have provided clear evidence for stimulus-specific neural priming, which in turn implicates perceptual brain mechanisms in the observed priming effects. Studies focusing on early visual areas have provided one source of such evidence. Grill-Spector et al. (1999) found that activation reductions in early visual areas such as posterior lateral occipital complex (LOC) exhibit a high degree of stimulus specificity for changes in viewpoint, illumination, size, and position. By contrast, later and more anterior aspects of LOC exhibit greater invariance across changes in size and position relative to illumination and viewpoint. Evidence from a study by Vuilleumier et al. (2005) considered in the previous section likewise indicates a high degree of stimulus specificity in early visual areas, as indicated by viewpoint-specific neural priming in these regions.

Later visual regions can also show stimulus-specific neural priming, but several studies indicate that this specificity effect is lateralized. In a study by Koutstaal et al. (2001), subjects judged whether pictures of common objects were larger than a 13-inch-square box, and later made the same judgments for identical objects, different exemplars of objects with the same name, and new objects. Behavioral priming, indicated by faster response times, occurred for both identical objects and different exemplars, with significantly greater priming for identical objects. Reductions in activation were also greater for same than for different exemplars in the bilateral middle occipital, parahippocampal, and fusiform cortices. These stimulus-specific activation reductions for object priming were greater in the right than in the left fusiform cortex. Simons et al. (2003) replicated these results and further demonstrated that left fusiform cortex shows more neural priming for different exemplars compared with novel items relative to right fusiform cortex, indicating more nonspecific neural priming in the left fusiform. Also, left but not right fusiform neural priming was influenced by a lexical-semantic manipulation (objects were accompanied by presentation of their names or by nonsense syllables), consistent with a lateralized effect in which right fusiform is modulated by specific physical features of target stimuli and left fusiform is influenced more strongly by semantic features. In a related study by Vuilleumier et al. (2002), subjects decided whether pictorial images depicted real or nonsense objects, and subsequently repeated stimuli were identical, differed in size or viewpoint, or were different exemplars with the same name. Neural priming in the right fusiform cortex was sensitive to changes in both exemplar and viewpoint.

A similar pattern has also been reported for orientation-specific object priming by Vuillemer et al. (2005) in the overlapping shape paradigm described earlier, and Eger et al. (2005) reported a stimulus-specific laterality effect using faces. In the latter experiment, subjects made male/female judgments about famous or unfamiliar faces that were preceded by the identical face, a different view of the same face, or an entirely different face. Behavioral priming, indexed by decreased response times, was greater for same than different viewpoints for both famous and unfamiliar faces. Collapsed across famous and unfamiliar faces, neural priming was more viewpoint dependent in right fusiform gyrus than in left fusiform gyrus. In addition, for famous faces, priming was more nonspecific in anterior than more posterior fusiform cortex. Similarly, Vuillemer et al. (2005) report some evidence for greater stimulus-specific neural priming in posterior compared with anterior fusiform gyrus. Other studies indicate that later perceptual regions can exhibit largely nonspecific priming, both for visual stimuli such as scenes (Blondin and Lepage, 2005) and auditory words (Orfanidou et al., 2006; see also Badgaiyan et al., 2001). However, evidence provided by Bunzeck et al. (2005) suggests that effects in later perceptual regions are characterized by category specificity. In their study, subjects made male/female judgments about faces and indoor/outdoor judgments about scenes. Subjects responded more quickly to repeated faces and scenes compared with initial presentations, thus demonstrating behavioral priming. Face-responsive regions in fusiform and related areas showed selective activation reductions for repeated faces, whereas place-responsive regions in parahippocampal cortex showed decreases for repeated scenes.

By contrast, regions of inferior frontal gyrus and left inferior temporal cortex appear to respond invariantly to an item's perceptual features and are instead sensitive to its abstract or conceptual properties – even when the degree of perceptual overlap between initial and subsequent presentations of a stimulus is minimal to nonexistent. Neural priming has been observed in these regions during reading of mirror-reversed words initially presented in a normal orientation (Ryan and Schnyer, 2006) and also when silently reading semantically related word pairs, but not for pairs that are semantically unrelated (Wheatley et al., 2005). Consistent with this observation, neural priming in these regions is independent of stimulus modality (Buckner et al., 2000) and has even been observed when the modality differs between the first and second presentations of a stimulus (e.g., visual to auditory; Badgaiyan et al., 2001; Carlesimo et al., 2003).

Overall, then, the foregoing studies reveal a fairly consistent pattern in which neural priming in early visual regions exhibits strong stimulus specificity, whereas in later visual regions, right-lateralized stimulus specificity is consistently observed (for a similar pattern in a study of subliminal word priming, see Dehaene et al., 2001). These effects dovetail nicely with previous behavioral studies using divided-visual-field techniques that indicate that visually specific priming effects occur to a greater extent in the left visual field (right hemisphere) than in the right visual field (left hemisphere) (e.g., Marsolek et al., 1992, 1996).

The overall pattern of results from neuroimaging studies of stimulus specificity suggests that, consistent with a number of earlier cognitive theories (e.g., Roediger, 1990; Schacter, 1990, 1994; Tulving and Schacter, 1990), perceptual brain mechanisms do indeed play a role in certain kinds of priming effects.

### 2.33.4.2 Associative Specificity

Research concerning the cognitive neuroscience of associative specificity began with studies examining whether amnesic patients can show priming of newly acquired associations between unrelated words. For example, amnesic patients and controls studied pairs of unrelated words (such as window–reason or officer–garden) and then completed stems paired with study list words (window–rea___) or different unrelated words from the study list (officer–rea___). Mildly amnesic patients and control subjects showed more priming when stems were presented with the same words from the study task than with different words, indicating that specific information about the association between the two words had been acquired and influenced priming, but severely amnesic patients failed to show associative priming (Graf and Schacter, 1985; Schacter and Graf, 1986). A number of neuropsychological studies have since examined associative specificity in amnesics with mixed results (for review, see Schacter et al., 2004), and it has been suggested that medial temporal lobe (MTL) structures play a role in such effects. Some relevant evidence has been provided by a PET study that used a blocked design version of the associative stem completion task (Badgaiyan et al., 2002). Badgaiyan et al. found that, as in previous behavioral studies, priming was greater when stems were paired with the same words as during the study task than when they were paired with different words. The same pairing condition produced greater activation in the right MTL than did the different pairing condition, suggesting that associative specificity on the stem completion task may indeed be associated with aspects of explicit memory. Given the paucity of imaging evidence concerning associative specificity, additional studies will be needed before any strong conclusions can be reached.

### 2.33.4.3 Response Specificity

While numerous behavioral studies had explored stimulus specificity and associative specificity prior to the advent of neuroimaging studies, the situation is quite different when considering response specificity, where changing the response or decision made by the subject about a particular item influences the magnitude of priming (note that we use the terms 'response specificity' and 'decision specificity' interchangeably, since behavioral data indicate that the effect is likely not occurring at the level of a motor response; see Schnyer et al., in press). Recent interest in response specificity has developed primarily as a result of findings from neuroimaging research. Dobbins et al. (2004) used an object decision priming task that had been used in studies considered earlier (Koutstaal et al., 2001; Simons et al., 2003), but modified the task so that responses either remained the same or changed across repeated trials. In the first scanning phase, pictures of common objects were either shown once or repeated three times, and subjects indicated whether each stimulus was bigger than a shoebox (using a 'yes' or 'no' response). Next, the cue was inverted so that subjects now indicated whether each item was 'smaller than a shoebox'; they made this judgment about new items and a subset of those that had been shown earlier. Finally, the cue was restored to 'bigger than a shoebox,' and subjects were tested on new items and the remaining items from the initial phase.

If priming-related reductions in neural activity that are typically produced by this task represent facilitated size processing, attributable to 'tuning' of relevant aspects of neural representations, then cue reversal should have little effect on priming (though it could disrupt overall task performance by affecting both new and primed items). According to the neural tuning account, the same representations of object size should be accessed whether the question focuses on 'bigger' or 'smaller' than a shoebox. By contrast, if subjects perform this task by rapidly recovering prior responses, and this response learning mechanism bypasses the need to recover size representations, then the cue reversal should disrupt priming-related reductions. When the cue is changed, subjects would have to abandon the learned responses and instead reengage the target objects in a controlled manner in order to recover size information.

During the first scanning phase, standard priming-related activation reductions were observed in both anterior and posterior regions previously linked with priming: left prefrontal, fusiform, and extrastriate regions. But when the cue was reversed, these reductions were eliminated in the left fusiform cortex and disrupted in prefrontal cortex; there was a parallel effect on behavioral response times. When the cue was restored to the original format, priming-related reductions returned (again there was a parallel effect on behavioral response times), suggesting that the reductions depended on the ability of subjects to use prior responses during trials. Accordingly, the effect was seen most clearly for items repeated three times before cue reversal.

Although this evidence establishes the existence of response-specific neural and behavioral priming, there must be limitations on the effect, since a variety of priming effects occur when participants make different responses during study and test. For instance, priming effects on the stem completion task, where subjects respond with the first word that comes to mind when cued with a three-letter word beginning, are typically observed after semantic or perceptual encoding tasks that require a different response (see earlier discussion on top-down attentional influences). Nonetheless, the existence of response specificity challenges the view that all activation reductions during priming are attributable to tuning or sharpening of perceptual representations, since such effects should survive a response change. Moreover, these findings also appear to pose problems for theories that explain behavioral priming effects on object decision and related tasks in terms of changes in perceptual representation systems that are thought to underlie object representation (e.g., Schacter, 1990, 1994; Tulving and Schacter, 1990), since these views make no provisions for response specificity effects. By contrast, the transfer appropriate processing view (e.g., Roediger et al., 1989, 1999) inherently accommodates such effects. According to this perspective, priming effects are maximized when the same processing operations are performed at study and at test. Although this view has emphasized the role of overlapping perceptual operations at study and at test to explain priming effects on tasks such as object decision, to the extent that the subject's decision or response is an integral part of encoding operations, it makes sense that reinstating such operations at test would maximize priming effects.

However, there is one further feature of the experimental paradigm that Dobbins et al. (2004) used to produce response specificity that complicates any simple interpretation. Priming in cognitive studies is usually based on a single study exposure to a target item, but neuroimaging studies of priming have typically used several study exposures in order to maximize the signal strength. As noted earlier, Dobbins et al. found that response specificity effects were most robust for items presented three times during the initial phase of the experiment (high-primed items), compared with items presented just once (low-primed items).

A more recent neuropsychological investigation of response specificity in amnesic patients highlights the potential theoretical importance of this issue (Schnyer et al., 2006). Schnyer et al. compared amnesics and controls on a variant of the object decision task used by Dobbins et al. (2004). Objects were presented either once (low primed) or thrice (high primed), and then responses either remained the same ('bigger than a shoebox?') or were switched ('smaller than a shoebox?'). Consistent with Dobbins et al. (2004), controls showed greater response specificity for high-primed objects compared with low-primed objects. Amnesic patients showed no evidence of response specificity, demonstrating normal priming for low-primed items and impaired priming for high-primed items. That is, healthy controls showed greater priming for high- than for low-primed objects in the same response condition, but amnesics failed to show this additional decrease in response latencies.

These results raise the possibility that different mechanisms are involved in priming for objects presented once versus those presented multiple times. Perhaps single-exposure priming effects on the object decision task depend primarily on perceptual systems that operate independently of the MTL and thus are preserved in amnesic patients. In neuroimaging experiments, such effects might reflect tuning or sharpening of perceptual systems, independent of the specific responses or decisions that subjects make regarding the object. But for items presented several times, subjects may learn to associate the object with a particular response, perhaps requiring participation of medial temporal and prefrontal regions. These considerations also suggest that response or decision specificity in the object decision paradigm used by Dobbins et al. (2004) is better described in terms of stimulus-response or stimulus-decision specificity – that is, the formation of a new link between a particular stimulus and the response or decision. This idea is supported by recent behavioral data showing that response-specific priming occurs only for the exact object that was studied, and not for a different exemplar with the same name (Schnyer et al., in press). In any event, the overall pattern of results suggests that a single-process model is unlikely to explain all aspects of these neural or behavioral priming effects, a point to which we return later in the chapter.

## 2.33.5 Priming-Related Increases in Neural Activation

Our review so far has focused on behavioral facilitation and corresponding repetition-related reductions of neural activity associated with priming. However, under some conditions, priming has been associated with decrements in stimulus processing, such as slower responses to previously ignored stimuli relative to novel stimuli (i.e., the 'negative priming' effect – a term coined by Tipper, 1985) and poorer episodic encoding for highly primed items (Wagner, et al., 2000). Further, while repetition-related increases in neural activity have long been associated with explicit memory processes, neural increases associated with priming have also been documented, although less frequently. Neuroimaging studies have begun to investigate the nature of such neural increases and the conditions that elicit them. This research suggests a link between performance decrements and increased neural responses associated with priming and provides new evidence that speaks to competing cognitive theories of implicit memory.

### 2.33.5.1 Negative Priming

Negative priming (NP) occurs when a stimulus is initially ignored, and subsequent processing of the stimulus is impaired relative to that of novel stimuli. An early example of identity NP was demonstrated by Tipper (1985); overlapping drawings of objects drawn in two different colors were presented, and subjects were instructed to attend to and identify objects of only one specified color. At test, identification of previously presented objects that were ignored was significantly slower than identification of novel objects. The NP effect has since been documented across a diverse range of experimental tasks and stimuli (for review, see Fox, 1995; May et al., 1995). Efforts to characterize the nature of this processing have sparked a number of theoretical debates within the cognitive psychology literature. One of these debates has centered on the cause of NP (e.g., whether it relies on processes during encoding or later retrieval), while another has focused on determining the level of processing that ignored items undergo in order to elicit NP (e.g., perceptual vs. semantic processing).

Competing accounts of the cause of NP are offered by two theories. The selective inhibition model (Houghton and Tipper, 1994) proposes that representations of ignored stimuli are initially activated but are immediately inhibited thereafter by selective attention. Thus, upon subsequent presentation of a previously ignored stimulus, this inhibition must be overcome, resulting in slowed processing relative to novel stimuli. The episodic retrieval model (Neill and Valdes, 1992; Neill et al., 1992) proposes that ignored stimuli are fully encoded into an episodic representation, as are attended stimuli. Upon repeated presentation of a stimulus, episodic information from the initial presentation can provide a 'shortcut' to the previous response associated with that stimulus. Whereas this would facilitate processing of previously attended stimuli that were associated with a particular response, it is detrimental to processing of ignored stimuli with which no response was associated at study. Behavioral experiments have failed to produce unambiguous support for either of these models (Fox, 1995; May et al., 1995; Egner and Hirsch, 2005).

Neuroimaging can provide a useful way to test these theories, because they predict the involvement of different brain regions supporting either inhibitory or episodic processes. Egner and Hirsch (2005) reported data from an fMRI experiment using a color-naming Stroop task that provide support for the episodic retrieval model. A region in the right dorsolateral prefrontal cortex (DLPFC) demonstrated increased activation for probe trials that were subject to NP relative to probe trials that had not been primed. The authors noted that this right DLPFC region has been associated with processes related to episodic retrieval (for review, see Stevens and Grady, 2007). Importantly, across individual subjects, activity in right DLPFC was positively correlated with response times during NP trials, but not nonprimed trials. These data support the theory that ignored stimuli, rather than being actively inhibited, are fully encoded at study, and that episodic retrieval at test contributes to the NP effect.

Another recent fMRI study investigated the level at which ignored stimuli are processed (i.e., perceptual vs. semantic/abstract) (Zubicaray et al., 2006). The authors reasoned that, if ignored stimuli elicit automatic activation of semantic representations at study, then brain regions that have been implicated in the storage and/or processing of these representations, such as the anterior temporal cortex (for review, see McClelland and Rogers, 2003) should be active during study of ignored stimuli. Overlapping drawings of different-colored objects elicited NP (slower reaction time for object identification at test) for previously ignored objects relative to novel objects. Analysis of fMRI data from the study session revealed a positive relationship between the magnitude of BOLD activity in the left anterolateral temporal cortex, including the temporal pole, and the magnitude of the subsequent NP effect. In agreement with Egner and Hirsch (2005), these data suggest that ignored stimuli are actively processed at study, and further indicate that this processing occurs at the level of abstract/semantic representations in higher conceptual brain regions.

### 2.33.5.2 Familiar Versus Unfamiliar Stimuli

There has been a long-standing debate in the cognitive psychology literature concerning priming of familiar versus unfamiliar stimuli (for review, see Tenpenny, 1995). According to modification/abstractionist theories (Morton, 1969; Bruce and Valentine, 1985), preexisting representations are required in order for priming to occur; these abstract representations are modified in some way upon presentation of familiar stimuli. According to acquisition/episodic theories (Jacoby, 1983; Roediger and Blaxton, 1987; Schacter et al., 1990), priming does not rely on a preexisting representation; rather, both familiar and unfamiliar stimuli can leave some form of a trace that can facilitate subsequent priming (although there may be limits; see Schacter et al., 1990; Schacter and Cooper, 1995). Neuroimaging studies have produced data relevant to this debate.

In a PET study, Schacter et al. (1995) reported behavioral priming for repeated unfamiliar objects, as shown by increased accuracy of possible/impossible judgments for structurally possible three-dimensional objects. However, in contrast to the more common finding of concomitant reduction in neural activity associated with behavioral priming reviewed earlier in the chapter, the authors reported increased activation in a left inferior fusiform region that was associated with priming of the possible objects.

In a more recent event-related fMRI study, Henson et al. (2000) reported data from four experiments using familiar and unfamiliar faces and symbols that directly tested the hypothesis that repetition-related neural priming entails reduced neural activity for familiar stimuli, but increased neural activity for unfamiliar stimuli. Behavioral priming (faster reaction times for familiarity judgments) was documented for repetition of both familiar and unfamiliar faces and symbols (although priming was greater for familiar than for unfamiliar stimuli). However, in a right fusiform region, repetition resulted in decreased activation for familiar faces and symbols, but increased activation for unfamiliar faces and symbols.

Henson et al. (2000) offered an account of their findings in terms of both modification and acquisition: while priming of familiar stimuli involves modification of preexisting representations, resulting in repetition suppression, priming also occurs for unfamiliar stimuli as a new representation is formed, resulting in repetition enhancement (for a generalized theory, see Henson, 2003). This suggestion is supported by evidence from a study by Fiebach et al. (2005), who concluded that neural decreases accompanying repeated words, in contrast to neural increases accompanying repeated pseudowords, reflect the sharpening of familiar object representations and the formation of novel representations for unfamiliar objects, respectively. Further, data from a previously reviewed study by Ishai et al. (2004) support this hypothesis as well; for unfamiliar faces, neural activation increased for the first repetition, but decreased in a linear trend thereafter, possibly reflecting the initial acquisition of an unfamiliar face representation, followed by subsequent modification of this newly formed representation. Henson et al. (2000) further hypothesized that the repetition enhancement effect for unfamiliar stimuli would only occur in "higher visual areas, such as the fusiform cortex, where the additional processes such as recognition occur" (Henson et al., 2000: 1272). However, in a recent study using event-related fMRI, Slotnick and Schacter (2004) reported increased activation in early visual processing regions (BA 17/18) for repeated, relative to novel, unfamiliar abstract shapes. This finding suggests that earlier perceptual regions may also demonstrate activation attributable to processes involved in acquisition of new representations of unfamiliar stimuli.

### 2.33.5.3 Sensitivity Versus Bias

In number of studies by Schacter and colleagues (Schacter et al., 1990, 1991a; Cooper et al., 1992; Schacter and Cooper, 1993) participants studied line drawings of structurally possible and impossible objects and then made possible/impossible judgments at test to repeated presentations of the objects. Behavioral priming is measured as increased accuracy (and/or faster reaction time) for identifying an object as possible or impossible upon repeated presentations; significant priming is consistently observed for possible, but not impossible, objects. As mentioned earlier, a PET study of priming on the possible/impossible decision task revealed that increased activation in a left inferior/fusiform region was associated with priming of possible objects only (Schacter et al., 1995).

Schacter and Cooper proposed that such priming depends on the structural description system (SDS), a subsystem of the more general perceptual representation system (Tulving and Schacter, 1990). The proposal of an SDS was based on evidence of dissociations between priming (for possible, but not impossible, objects) and explicit tests of memory, across study-to-test object transformations (Cooper, et al., 1992; Schacter et al., 1993b), manipulations at encoding (Schacter and Cooper, 1993; Schacter et al., 1990), and in studies with elderly populations and amnesic patients (Schacter et al., 1991b, 1992, 1993b; and for review, see Soldan et al., 2006). In this view, priming of repeated objects reflects increased sensitivity (i.e., accuracy) on the part of the SDS, which is only capable of representing structurally possible objects.

An alternative theory is the bias account of priming in the possible/impossible object-decision task proposed by Ratcliff and McKoon (McKoon and Ratcliff, 1995, 2001; Ratcliff and McKoon, 1995, 1996, 1997, 2000). In this view, an encounter with an object, regardless of whether it is structurally possible or impossible, results in a subsequent bias to classify that object as 'possible,' leading to increased accuracy (i.e., positive priming) for repeated possible objects but decreased accuracy (i.e., negative priming) for impossible objects. However, this account also posits that explicit processes play a role in object-decisions, such that explicit memory of the study episode cues subjects as to whether the object is possible or impossible. It is argued, then, that this combination of bias and episodic information leads to robust positive priming for possible objects. By contrast, for impossible objects, the two factors cancel each other out, resulting in zero priming. Ratcliff and McKoon (1995) reported data from seven experiments that supported their hypothesis (for criticism of their conclusions, see Schacter and Cooper, 1995; for response, see McKoon and Ratcliff, 1995). Other bias accounts of object-decision priming have been proposed as well, such as the structure-extraction bias (Williams and Tarr, 1997).

Behavioral studies relevant to this debate continue to emerge, supporting either the sensitivity account of priming (e.g., Zeelenberg et al., 2002) or the bias account (e.g., Thapar and Rouder, 2001), but behavioral investigations alone have been inconclusive (Soldan et al., 2006). However, neuroimaging studies have recently produced evidence that speaks to the ongoing debate.

In a recent event-related fMRI study (Habeck et al., 2006), subjects performed a continuous possible/impossible object-decision task on structurally possible and impossible objects repeated four times each. Although the behavioral results did not correspond to sensitivity or bias models, or to previous findings (priming, as measured by faster reactions times, was documented for both possible and impossible objects), neural priming was documented for possible objects only. A multivariate analysis of the fMRI data revealed a pattern of brain regions in which activation covaried in a linear fashion (areas showing both repetition suppression and repetition enhancement) with repetition of possible objects only. No such pattern was observed for repetition of impossible objects. Further, there was a correlation between behavioral (faster reaction times) and neural priming for possible objects only.

Similarly, a recent ERP study by Soldan et al. (2006) reported data from two possible/impossible object-decision priming experiments using unfamiliar objects that provide compelling evidence that the visual system differentially encodes globally possible versus globally impossible structures. In the first experiment, subjects made structural decisions (right/left orientation-decision task) about possible and impossible objects at study. In the second experiment, a functional decision (tool/support function-decision task) was performed at study. The behavioral results of the experiments were inconclusive with respect to sensitivity versus bias theories. However, the ERP data clearly failed to support bias theories, which hold that possible and impossible objects are processed similarly in the visual processing system. Rather, two early ERP components (the N1 and N2 responses) showed repetition enhancement for possible objects, but no neural effect for repetition of impossible objects, in both the structural and functional encoding experiments. Moreover, the magnitude of repetition enhancement in the N1 ERP component was correlated with behavioral priming for possible objects. These data support the theory that priming is supported by an SDS that encodes structurally possible objects only.

## 2.33.6 Correlations between Behavioral and Neural Priming

While neuroimaging studies have provided considerable evidence bearing on the neural correlates of priming, caution is warranted when interpreting the causal nature of such effects. Although a number of studies have documented the close overlap between neuronal activity and BOLD activity in the primate (Logothetis et al., 2001; Shmuel et al., 2006; for a human analogue see Mukamel et al., 2005), it is critical to determine whether functional neuroimaging data reflect the neural underpinnings of cognitive processes or index spurious activations that are epiphenomenal to the process of interest.

Initial studies used methodologies where blocks during which participants viewed repeated items were contrasted with blocks during which participants viewed novel items (e.g., Squire et al., 1992; Raichle et al., 1994; Buckner et al., 1995; Schacter et al., 1996; Wagner et al., 1997). The introduction of event-related fMRI (Dale and Buckner, 1997) later allowed researchers to intermix old and new items and delineate activity associated with individual trial-types, providing evidence that the neural priming that accompanies repeated items is not simply due to a blunting of attention or vigilance that may permeate extended periods of cognitive processing (e.g., Buckner et al., 1998). Together, studies of this sort have consistently documented the co-occurrence of behavioral priming and neural priming in a subset of the brain regions that are engaged during task performance with novel material (see **Figure 1**).

In order to establish a link between neural priming and behavioral priming, neuroimaging studies have attempted to demonstrate a relationship between the magnitude of both effects. That is, if neural priming is indeed related to behavioral priming, then the two should not only co-occur but should be directly correlated. A number of studies have reported a positive correlation between the magnitudes of behavioral priming and neural priming in frontal regions during tasks of a semantic or conceptual nature. Maccotta and Buckner (2004) showed that behavioral priming for repeated words in a living/nonliving classification task was significantly correlated with the magnitude of neural priming in regions of the left inferior frontal gyrus and pre-supplementary motor areas. Using the same task, Lustig and Buckner (2004) documented significant correlations between behavioral and neural priming in the left inferior frontal gyrus for young adults, healthy older adults, and patients with Alzheimer's disease (also see Golby et al., 2005). A similar pattern has been documented in the auditory domain: Orfanidou et al. (2006) found that the degree of auditory word priming on a lexical decision task was predicted by the extent of neural priming in left inferior frontal gyrus and supplementary motor areas. Others have found that the correlation between behavioral priming and prefrontal neural priming can be category specific. Using a classification task, Bunzeck et al. (2006) provided evidence that the correlations between neural and behavioral priming were specific for scenes in left inferior prefrontal cortex, but for faces in left middle frontal gyrus.

Consistent with the foregoing findings, in the aforementioned study by Dobbins et al. (2004), multiple regression analysis revealed that left prefrontal activity predicted the disruptive effects of response switching on behavioral priming for individual subjects: greater initial reductions in prefrontal activity were associated with greater subsequent disruptions of behavioral response times when the response was changed. To the extent that activation reductions in prefrontal cortex indicate less reliance on controlled processing and greater reliance on automatic processing, these data suggest that performance disruptions attributable to response switching reflect a need to

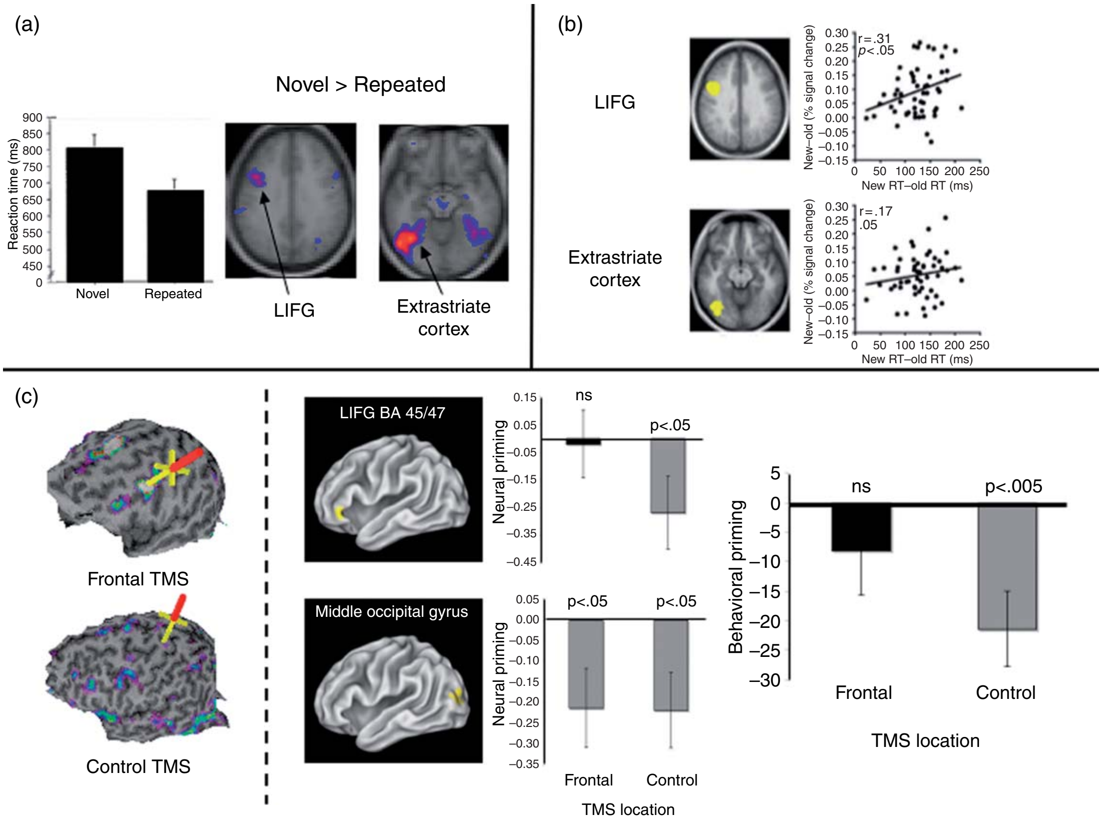


**Figure 1** Correlations between behavioral and neural priming. (a) Semantic classification of visual objects using event-related fMRI reveals that the decrease in response time (behavioral priming) that accompanies classification of repeated items co-occurs with decreased activity (neural priming) in regions of the left inferior frontal gyrus (LIFG) and extrastriate cortex. (b) During semantic classification of words, the magnitude of behavioral priming is directly correlated with the magnitude of neural priming in the LIFG, but not the extrastriate cortex. (c) Transcranial magnetic stimulation (TMS) applied to a region of the LIFG (but not of a control location) during semantic classification of visual objects disrupts subsequent behavioral priming and the neural priming in LIFG during fMRI scanning. Neural priming in the middle occipital gyrus is unaffected by frontal or control TMS. Adapted from (a) Buckner RL, Goodman J, Burock M, et al. (1998) Functional-anatomic correlates of object priming in humans revealed by rapid presentation event-related fMRI. *Neuron* 20: 285–296, with permission from Elsevier; (b) Maccotta L and Buckner RL (2004) Evidence for neural effects of repetition that directly correlate with behavioral priming. *J. Cogn. Neurosci.* 16: 1625–1632, with permission from MIT Press; (c) Wig GS, Grafton ST, Demos KE, and Kelley WM (2005) Reductions in neural activity underlie behavioral components of repetition priming. *Nat. Neurosci.* 8: 1228–1233, with permission from the authors.

reengage slower controlled processes in order to make object decisions. This idea is consistent with the further finding that reductions in fusiform activity did not predict behavioral costs of switching cues, suggesting that these reductions may be incidental to behavioral priming during conceptual tasks.

Other evidence indicates that behavioral priming can correlate with neural priming in regions outside the prefrontal cortex as well. Bergerbest et al. (2004) found that behavioral priming for environmental sound stimuli correlated with neural priming in right inferior prefrontal cortex and also in two secondary auditory regions: bilateral superior temporal sulci and right superior temporal gyrus. Using a stem completion task, Carlesimo et al. (2003) found that the magnitude of behavioral cross-modality priming (auditory-to-visual) was correlated with the extent of activation reduction at the junction of the left fusiform and inferior temporal gyrus.

Turk-Browne et al.'s (2006) study of the relation between priming and subsequent memory effects, (where, as discussed earlier, neural activity during encoding is sorted according to whether items are subsequently remembered or forgotten) provided a different perspective on the correlation issue. Repeated scenes produced behavioral and neural priming, but only for those scenes that were subsequently remembered. For these scenes only, there was also a correlation between the magnitude of behavioral and neural priming in the fusiform gyrus; this relationship approached significance in right inferior prefrontal cortex. As discussed earlier, the finding that the degree of behavioral and neural priming depended on subsequent memory points toward a link between implicit and explicit memory, perhaps involving shared attentional processes.

Together, these studies provide evidence for a relationship between behavioral priming and neural priming (also see Zago et al., 2005; Habeck et al., 2006). Correlations between the two variables generalize across paradigms (e.g., semantic classification, stem-completion) and are restricted to regions thought to mediate the cognitive operations engaged during the task. Although these correlations have been consistently reported with respect to neural priming in frontal cortices and to a lesser extent temporal cortex, few studies thus far have provided evidence for a correlation between behavioral priming and neural priming in earlier perceptual cortices – even though neural priming in the latter regions frequently accompanies item repetition.

The relationship between behavioral priming and neural priming in early visual regions was explicitly explored by Sayres and Grill-Spector (2006). Participants were scanned using fMRI in an adaptation paradigm during a semantic classification task on objects. Repetition of objects was accompanied by reductions in activity in regions of the LOC and posterior fusiform gyrus. However, in contrast to the correlations that have been observed between neural and behavioral priming in frontal and temporal regions, neural priming in earlier visual regions was unrelated to the facilitation in response time that accompanied repeated classification, thus providing more evidence that these two phenomena may be less tightly associated in these regions.

Although these correlations suggest that neural priming effects in prefrontal and temporal regions may support behavioral priming on a number of tasks, they do not allow conclusions regarding a causal role. It is possible that neural priming in these regions is necessary for behavioral priming. Alternatively, neural priming in other areas of the brain (e.g., regions of perceptual cortex) may subserve behavioral priming, and the neural priming observed in prefrontal and temporal cortex may simply reflect a feedforward propagation of the changes occurring in these other regions. In order to establish a causal relationship between behavioral priming and neural priming in frontal and temporal cortex, one would have to provide evidence of a disruption of behavioral and neural priming in these regions, accompanied by intact neural priming in perceptual cortices.

Wig et al. (2005) provided such evidence by combining fMRI with transcranial magnetic stimulation (TMS). TMS allows for noninvasive disruption of underlying cortical activity to a circumscribed region, thus inducing a reversible temporary virtual lesion (Pascual-Leone et al., 2000). In the study by Wig and colleagues, for each participant, regions of the left prefrontal cortex (along the inferior frontal gyrus) that demonstrated neural priming were first identified during semantic classification (living/nonliving) of repeated objects using fMRI. Each participant was then brought back for a TMS session where they classified a new set of objects using the same task. Short trains of TMS were applied to the previously identified prefrontal region during classification of half of these objects; classification of the remaining half of objects was accompanied by TMS applied to a control region (left motor cortex). Immediately following the TMS session, subjects were rescanned with fMRI while performing the semantic classification task on objects that were previously accompanied by prefrontal stimulation, objects previously accompanied by control-site stimulation, and novel objects. Results revealed that classification of objects that had been previously accompanied by left frontal TMS failed to demonstrate subsequent behavioral priming and neural priming in the left inferior frontal gyrus and lateral temporal cortex. By contrast, neural priming in early visual regions remained intact. Critically, these effects were not due to generalized cortical disruption that accompanied TMS; control-site stimulation had no disruptive effects on either behavioral or neural markers of priming. Consistent with this finding, Thiel et al. (2005) provided evidence for a disruptive effect of left-frontal TMS on behavioral priming during a lexical decision task. Together, these results provide evidence that behavioral and neural markers of priming in frontal and temporal regions are causally related, not just correlated.

In summary, correlations between behavioral and neural priming are observed consistently in prefrontal, and to some extent temporal, regions on priming tasks that include a conceptual component, such as semantic classification and stem completion. Although studies using such tasks have failed to demonstrate a relationship between behavioral priming and neural priming in perceptual regions, behavioral demonstrations of perceptual priming are well documented (e.g., Tulving and Schacter, 1990; Schacter et al., 1993a). A key hypothesis to be evaluated in future investigations is that neural priming in perceptual cortices subserves perceptual priming. Establishing a causal relationship between the two necessitates careful consideration of the behavioral tasks used to demonstrate such effects. Further, it is likely that the behavioral advantage for repeated processing of an item is mediated by multiple processes and components of priming – both conceptual and perceptual – that contribute in an aggregate fashion to facilitate task performance (e.g., Roediger et al., 1999). Neuroimaging research can be helpful in attempting to tease apart the components of such effects and link them with the activity of specific brain regions.

## 2.33.7 Summary and Conclusions

Our review demonstrates that neuroimaging research has shed new light on cognitive theories of priming that were originally formulated and investigated through behavioral approaches within the field of cognitive psychology. The contributions of this research include advances with respect to long-standing theoretical debates about the nature of priming, as well as new lines of investigation not previously addressed by cognitive studies.

As alluded to earlier, evidence across several domains of neuroimaging research on priming is inconsistent with a single process account of the phenomenon, and instead supports the idea that multiple processes are involved in different types of behavioral priming and corresponding neural priming. Schacter et al. (2007) recently proposed a multiple-component view of priming, as depicted in **Figure 2**.

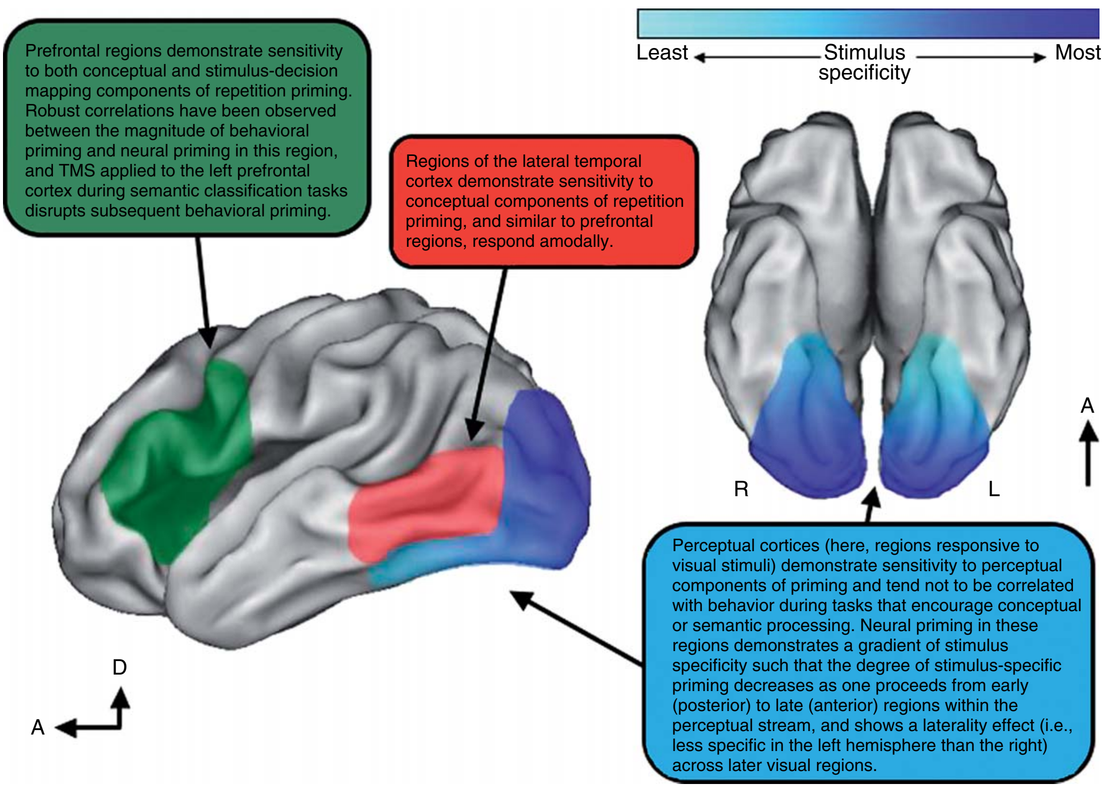


**Figure 2** Schematic of proposed components of priming. Figure depicts partially inflated lateral view of the left hemisphere and ventral view of the left and right hemispheres. Lateral view is tilted in the dorsal-ventral plane to expose the ventral surface ('A' denotes anterior direction, 'D' denotes dorsal direction, 'L' and 'R' denote left and right hemispheres, respectively). Color-coding of anatomical regions is meant to serve as a heuristic for the proposed components. The color gradient within the ventral visual stream (blue) is meant to represent approximately the gradient of stimulus specificity that has been observed within these regions. TMS, transcranial magnetic stimulation. Adapted from Schacter DL, Wig GS, and Stevens WD (2007) Reductions in cortical activity during priming. *Curr. Opin. Neurobiol*. 17: 171–176, with permission from Elsevier.

This view suggests that there are at least two distinct mechanisms involved in neural priming. One corresponds roughly to what Wiggs and Martin (1998) called *sharpening* or *tuning*, which occurs when exposure to a stimulus results in a sharper, more precise neural representation of that stimulus (*See* Chapter 3.12; see also Grill-Spector et al. (2006) for more detailed consideration of sharpening and related ideas). Such tuning effects are likely to predominate in posterior regions that code for the perceptual representations of items, and perhaps in anterior regions that underlie conceptual properties of these items. Tuning effects, however, are unable to account for response-specific priming effects (e.g., Dobbins et al., 2004) and appear to be less correlated with behavioral priming observed during tasks that are semantic or conceptual in nature. The second proposed mechanism primarily reflects changes in prefrontal cortex that drive behavioral priming effects in a top-down manner, as initially controlled processes become more automatic (Logan, 1990; Dobbins et al., 2004).

While the view proposed by Schacter et al. (2007) suggests two possible components of priming, this is a preliminary model that needs to be extended, elaborated, and related more fully to distinctions among types of priming (e.g., perceptual, conceptual, associative) that have been long discussed in the cognitive literature. Traditional theories of priming laid the groundwork for understanding these components, and neuroimaging research will likely play a crucial role in resolving the questions that remain, in suggesting new lines of inquiry not previously conceived of, and in expanding our understanding of the nature of priming and implicit memory more generally.

## References


Badgaiyan RD, Schacter DL, and Alpert NM (1999) Auditory priming within and across modalities: Evidence from positron emission tomography. *J. Cogn. Neurosci.* 11: 337–348.

Badgaiyan RD, Schacter DL, and Alpert NM (2001) Priming within and across modalities: Exploring the nature of rCBF increases and decreases. *Neuroimage* 13: 272–282.

Badgaiyan RD, Schacter DL, and Alpert NM (2002) Retrieval of relational information: A role for left inferior prefrontal cortex. *Neuroimage* 17: 393–400.

Bergerbest D, Ghahremani DG, and Gabrieli JD (2004) Neural correlates of auditory repetition priming: Reduced fMRI activation in the auditory cortex. *J. Cogn. Neurosci.* 16: 966–977.

Berntsen D and Hall NM (2004) The episodic nature of involuntary autobiographical memories. *Mem. Cognit.* 32: 789–803.

Blondin F and Lepage M (2005) Decrease and increase in brain activity during visual perceptual priming: An fMRI study on similar but perceptually different complex visual scenes. *Neuropsychologia* 43: 1887–1900.

Bowers BJ (2000) The modality-specific and -nonspecific components of long-term priming are frequency sensitive. *Mem. Cognit.* 28: 406–414.

Bowers JS and Schacter DL (1990) Implicit memory and test awareness. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 404–416.

Brewer JB, Zhao Z, Glover GH, and Gabrieli JD (1998) Making memories: Brain activity that predicts whether visual experiences will be remembered or forgotten. *Science* 281: 1185–1187.

Bruce V and Valentine T (1985) Identity priming in the recognition of familiar faces. *Br. J. Psychol.* 76: 373–383.

Buckner RL, Goodman J, Burock M, et al. (1998) Functional-anatomic correlates of object priming in humans revealed by rapid presentation event-related fMRI. *Neuron* 20: 285–296.

Buckner RL, Koutstaal W, Schacter DL, and Rosen BR (2000) Functional MRI evidence for a role of frontal and inferior temporal cortex in amodal components of priming. *Brain* 123: 620–640.

Buckner RL, Petersen SE, Ojemann JG, Miezin FM, Squire LR, and Raichle ME (1995) Functional anatomical studies of explicit and implicit memory retrieval tasks. *J. Neurosci.* 15: 12–29.

Bunzeck N, Schutze H, and Duzel E (2006) Category-specific organization of prefrontal response-facilitation during priming. *Neuropsychologia* 44: 1765–1776.

Bunzeck N, Wuestenberg T, Lutz K, Heinze HJ, and Jancke L (2005) Scanning silence: Mental imagery of complex sounds. *Neuroimage* 26: 1119–1127.

Carlesimo GA (1994) Perceptual and conceptual priming in amnesic and alcoholic patients. *Neuropsychologia* 32: 903–921.

Carlesimo GA, Bonanni R, and Caltagirone C (2003) Memory for the perceptual and semantic attributes of information in pure amnesic and severe closed-head injured patients. *J. Clin. Exp. Neuropsychol.* 25: 391–406.

Carlesimo GA, Turriziani P, Paulesu E, et al. (2004) Brain activity during intra- and cross-modal priming: New empirical data and review of the literature. *Neuropsychologia* 42: 14–24.

Clarke R and Morton J (1983) Cross modality facilitation in tachistoscopic word recognition. *Q. J. Exp. Psychol.* 35A: 79–96.

Cooper LA, Schacter DL, Ballesteros S, and Moore C (1992) Priming and recognition of transformed three-dimensional objects: Effects of size and reflection. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 43–57.

Dale AM and Buckner RL (1997) Selective averaging of rapidly presented individual trials using fMRI. *Hum. Brain Mapp.* 5: 329–340.

Dehaene S, Naccache L, Cohen L, et al. (2001) Cerebral mechanisms of word masking and unconscious repetition priming. *Nat. Neurosc.* 4: 752–758.

Dobbins IG, Schnyer DM, Verfaellie M, and Schacter DL (2004) Cortical activity reductions during repetition priming can result from rapid response learning. *Nature* 428: 316–319.

Duzel E, Richardson-Klavehn A, Neufang M, Schott BH, Scholz M, and Heinze HJ (2005) Early, partly anticipatory, neural oscillations during identification set the stage for priming. *Neuroimage* 25: 690–700.

Eger E, Henson RN, Driver J, and Dolan RJ (2004) Bold repetition decreases in object-responsive ventral visual areas depend on spatial attention. *J. Neurophysiol.* 92: 1241–1247.

Eger E, Schweinberger SR, Dolan RJ, and Henson RN (2005) Familiarity enhances invariance of face representations in

human ventral visual cortex: fMRI evidence. *Neuroimage* 26: 1128–1139.
Egner T and Hirsch J (2005) Where memory meets attention: Neural substrates of negative priming. *J. Cogn. Neurosci.* 17: 1774–1784.
Epstein R and Kanwisher N (1998) A cortical representation of the local visual environment. *Nature* 392: 598–601.
Fiebach CJ, Gruber T, and Supp GG (2005) Neuronal mechanisms of repetition priming in occipitotemporal cortex: Spatiotemporal evidence from functional magnetic resonance imaging and electroencephalography. *J. Neurosci.* 25: 3414–3422.
Fox E (1995) Negative priming from ignored distractors in visual selection: A review. *Psychon. Bull. Rev.* 2: 145–173.
Golby A, Silverberg G, Race E, et al. (2005) Memory encoding in Alzheimer's disease: An fMRI study of explicit and implicit memory. *Brain* 128: 773–787.
Graf P and Mandler G (1984) Activation makes words more accessible, but not necessarily more retrievable. *J. Verbal Learn. Verbal Behav.* 23: 553–568.
Graf P and Ryan L (1990) Transfer-appropriate processing for implicit and explicit memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 978–992.
Graf P and Schacter DL (1985) Implicit and explicit memory for new associations in normal subjects and amnesic patients. *J. Exp. Psychol. Learn. Mem. Cogn.* 11: 501–518.
Graf P, Shimamura AP, and Squire LR (1985) Priming across modalities and priming across category levels: Extending the domain of preserved functioning in amnesia. *J. Exp. Psychol. Learn. Mem. Cogn.* 11: 385–395.
Grill-Spector K, Henson R, and Martin A (2006) Repetition and the brain: Neural models of stimulus-specific effects. *Trends Cogn. Sci.* 10: 14–23.
Grill-Spector K, Kushnir T, Edelman S, Avidan G, Itzchak Y, and Malach R (1999) Differential processing of objects under various viewing conditions in the human lateral occipital complex. *Neuron* 24: 187–203.
Gruber T, Giabbiconi CM, Trujillo-Barreto NJ, and Muller MM (2006) Repetition suppression of induced gamma band responses is eliminated by task switching. *Eur. J. Neurosci.* 24: 2654–2660.
Habeck C, Hilton HJ, Zarahn E, Brown T, and Stern Y (2006) An event-related fMRI study of the neural networks underlying repetition suppression and reaction time priming in implicit visual memory. *Brain Res.* 1075: 133–141.
Hasson U, Nusbaum HC, and Small SL (2006) Repetition suppression for spoken sentences and the effect of task demands. *J. Cogn. Neurosci.* 18: 2013–2029.
Henson RN (2003) Neuroimaging studies of priming. *Prog. Neurobiol.* 70: 53–81.
Henson RN, Shallice T, and Dolan R (2000) Neuroimaging evidence for dissociable forms of repetition priming. *Science* 287: 1269–1272.
Henson RN, Shallice T, Gorno-Tempini ML, and Dolan RJ (2002) Face repetition effects in implicit and explicit memory tests as measured by fMRI. *Cereb. Cortex* 12: 178–186.
Houghton G and Tipper SP (1994) A model of inhibitory mechanisms in selective attention. In: Dagenbach D and Carr T (eds.) *Inhibitory Mechanisms in Attention, Memory, and Language*, pp. 53–112. San Diego, CA: Academic Press.
Ishai A, Pessoa L, Bikle PC, and Ungerleider LG (2004) Repetition suppression of faces is modulated by emotion. *Proc. Natl. Acad. Sci. USA* 101: 9827–9832.
Jacoby LL (1983) Perceptual enhancement: Persistent effects of an experience. *J. Exp. Psychol. Learn. Mem. Cogn.* 9: 21–38.
Jacoby LL (1991) A process dissociation framework: Separating automatic from intentional uses of memory. *J. Mem. Lang.* 30: 513–541.
Jacoby LL and Dallas M (1981) On the relationship between autobiographical memory and perceptual learning. *J. Exp. Psychol. Gen.* 110: 306–340.
Koutstaal W, Verfaellie M, and Schacter DL (2001) Recognizing identical vs. similar categorically related common objects: Further evidence for degraded gist representations in amnesia. *Neuropsychology* 15: 268–289.
Logan GD (1990) Repetition priming and automaticity: Common underlying mechanisms? *Cognit. Psychol.* 22: 1–35.
Logothetis NK, Pauls J, Augath M, Trinath T, and Oeltermann A (2001) Neurophysiological investigation of the basis of the fMRI signal. *Nature* 412: 150–157.
Lustig C and Buckner RL (2004) Preserved neural correlates of priming in old age and dementia. *Neuron* 42: 865–875.
Maccotta L and Buckner RL (2004) Evidence for neural effects of repetition that directly correlate with behavioral priming. *J. Cogn. Neurosci.* 16: 1625–1632.
Marsolek CJ, Kosslyn SM, and Squire LR (1992) Form specific visual priming in the right cerebral hemisphere. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 492–508.
Marsolek CJ, Schacter DL, and Nicholas CD (1996) Form-specific visual priming for new associations in the right cerebral hemisphere. *Mem. Cognit.* 24: 539–556.
Martin E (1968) Stimulus meaningfulness and paired-associate transfer: An encoding variability hypothesis. *Psychol. Rev.* 75: 421–441.
May CP, Kane MJ, and Hasher L (1995) Determinants of negative priming. *Psychol. Bull.* 118: 35–54.
McClelland JL and Rogers TT (2003) The parallel distributed processing approach to semantic cognition. *Nat. Rev. Neurosci.* 4: 310–322.
McKoon G and Ratcliff R (1995) How should implicit memory phenomena be modeled? *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 777–784.
McKoon G and Ratcliff R (2001) Counter model for word identification: Reply to Bowers (1999). *Psychol. Rev.* 108: 674–681.
Miller EK and Desimone R (1993) Scopolamine affects short-term memory but not inferior temporal neurons. *Neuroreport* 4: 81–84.
Miller EK, Gochin PM, and Gross CG (1991) Habituation-like decrease in the responses of neurons in inferior temporal cortex of the macaque. *Vis. Neurosci.* 7: 357–362.
Morton J (1969) Interaction of information in word recognition. *Psychol. Rev.* 76: 165–178.
Mukamel R, Gelbard H, Arieli A, Hasson U, Fried I, and Malach R (2005) Coupling between neuronal firing, field potentials, and fMRI in human auditory cortex. *Science* 309: 951–954.
Mulligan NW and Hartman M (1996) Divided attention and indirect memory tests. *Mem. Cognit.* 24: 453–465.
Mulligan NW and Hornstein SL (2000) Attention and perceptual priming in the perceptual identification task. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 626–637.
Murray SO and Wojciulik E (2004) Attention increases neural selectivity in the human lateral occipital complex. *Nat. Neurosci.* 7: 70–74.
Neill WT and Valdes LA (1992) Persistence of negative priming: Steady state of decay? *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 565–576.
Neill WT, Valdes LA, Terry KM, and Gorfein DS (1992) Persistence of negative priming: II. Evidence for episodic trace retrieval. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 993–1000.
O'Kane G, Insler RZ, and Wagner AD (2005) Conceptual and perceptual novelty effects in human medial temporal cortex. *Hippocampus* 15: 326–332.
Orfanidou E, Marslen-Wilson WD, and Davis MH (2006) Neural response suppression predicts repetition priming of spoken words and pseudowords. *J. Cogn. Neurosci.* 18: 1237–1252.

Pascual-Leone A, Walsh V, and Rothwell J (2000) Transcranial magnetic stimulation in cognitive neuroscience – virtual lesion, chronometry, and functional connectivity. *Curr. Opin. Neurobiol.* 10: 232–237.
Raichle ME, Fiez JA, Videen TO, et al. (1994) Practice-related changes in human brain functional anatomy during nonmotor learning. *Cereb. Cortex* 4: 8–26.
Ratcliff R and McKoon G (1995) Bias in the priming of object decisions. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 754–767.
Ratcliff R and McKoon G (1996) Bias effects in implicit memory tasks. *J. Exp. Psychol. Gen.* 125: 403–421.
Ratcliff R and McKoon G (1997) A counter model for implicit priming in perceptual word identification. *Psychol. Rev.* 104: 319–343.
Ratcliff R and McKoon G (2000) Modeling the effects of repetition and word frequency in perceptual identification. *Psychon. Bull. Rev.* 7: 713–717.
Richardson-Klavehn A and Gardiner JM (1996) Cross-modality priming in stem completion reflects conscious memory, but not voluntary memory. *Psychon. Bull. Rev.* 3: 238–244.
Richardson-Klavehn A and Gardiner JM (1998) Depth-of-processing effects on priming in stem completion: Tests of the voluntary-contamination, conceptual-processing, and lexical-processing hypotheses. *J. Exp. Psychol. Learn. Mem. Cogn.* 24: 593–609.
Richardson-Klavehn A, Gardiner JM, and Java RI (1994) Involuntary conscious memory and the method of opposition. *Memory* 2: 1–29.
Roediger HL III (1990) Implicit memory: A commentary. *Bull. Psychon. Soc.* 28: 373–380.
Roediger HL III and Blaxton TA (1987) Effects of varying modality, surface features, and retention interval on priming in word fragment completion. *Mem. Cognit.* 15: 379–388.
Roediger HL, Buckner RL III, and McDermott KB (1999) Components of processing. In: Foster JK and Jelicic M (eds.) *Memory: Systems, Process, or Function?* pp. 31–65. Oxford: Oxford University Press.
Roediger HL III and McDermott KB (1993) Implicit memory in normal human subjects. In: Spinnler H and Boller F (eds.) *Handbook of Neuropsychology*, pp. 63–131. Amsterdam: Elsevier.
Roediger HL III, Weldon MS, and Challis BH (1989) Explaining dissociations between implicit and explicit measures of retention: A processing account. In: Roediger HLI and Craik FIM (eds.) *Varieties of Memory and Consciousness: Essays in Honor of Endel Tulving*, pp. 3–41. Hillsdale, NJ: Erlbaum.
Rugg MD, Fletcher PC, Frith CD, Frackowiak RSJ, and Dolan RJ (1997) Brain regions supporting intentional and incidental memory: A PET study. *Neuroreport* 8: 1283–1287.
Ryan L and Schnyer D (2006) Regional specificity of format-specific priming effects in mirror word reading using functional magnetic resonance imaging. *Cereb. Cortex* 17: 982–992.
Sayres R and Grill-Spector K (2006) Object-selective cortex exhibits performance-independent repetition suppression. *J. Neurophysiol.* 95: 995–1007.
Schacter DL (1987) Implicit memory: History and current status. *J. Exp. Psychol. Learn. Mem. Cogn.* 13: 501–518.
Schacter DL (1990) Perceptual representation systems and implicit memory: Toward a resolution of the multiple memory systems debate. *Ann. N.Y. Acad. Sci.* 608: 543–571.
Schacter DL (1994) Priming and multiple memory systems: Perceptual mechanisms of implict memory. In: Schacter DL and Tulving E (eds.) *Memory Systems*, pp. 233–268. Cambridge: MIT Press.
Schacter DL, Badgaiyan RD, and Alpert NM (1999) Visual word stem completion priming within and across modalities: A PET study. *Neuroreport* 10: 2061–2065.
Schacter DL, Bowers J, and Booker J (1989) Intention, awareness, and implicit memory: The retrieval intentionality criterion. In: Lewandowsky S, Dunn JC, and Kirsner K (eds.) *Implicit Memory: Theoretical Issues*, pp. 47–69. Hillsdale, NJ: Erlbaum.
Schacter DL and Buckner RL (1998) Priming and the brain. *Neuron* 20: 185–95.
Schacter DL, Chiu CYP, and Ochsner KN (1993a) Implicit memory: A selective review. *Annu. Rev. Neurosci.* 16: 159–182.
Schacter DL and Church B (1992) Auditory priming: Implicit and explicit memory for words and voices. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 915–930.
Schacter DL and Cooper LA (1993) Implicit and explicit memory for novel visual objects: Structure and function. *J. Exp. Psychol. Learn. Mem. Cogn.* 19: 995–1009.
Schacter DL and Cooper LA (1995) Bias in the priming of object decisions: Logic, assumption, and data. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 768–776.
Schacter DL, Cooper LA, and Delaney SM (1990) Implicit memory for unfamiliar objects depends on access to structural descriptions. *J. Exp. Psychol. Gen.* 119: 5–24.
Schacter DL, Cooper LA, Delaney SM, Peterson MA, and Tharan M (1991a) Implicit memory for possible and impossible objects: Constraints on the construction of structural descriptions. *J. Exp. Psychol. Learn. Mem. Cogn.* 17: 3–19.
Schacter DL, Cooper LA, Tharan M, and Rubens AB (1991b) Preserved priming of novel objects in patients with memory disorders. *J. Cogn. Neurosci.* 3: 117–130.
Schacter DL, Cooper LA, and Treadwell J (1993b) Preserved priming of novel objects across size transformation in amnesic patients. *Psych. Sci.* 4: 331–335.
Schacter DL, Cooper LA, and Valdiserri M (1992) Implicit and explicit memory for novel visual objects in older and younger adults. *Psychol. Aging* 7: 299–308.
Schacter DL, Dobbins IG, and Schnyer DM (2004) Specificity of priming: A cognitive neuroscience perspective. *Nat. Rev. Neurosci.* 5: 853–862.
Schacter DL and Graf P (1986) Preserved learning in amnesic patients: Perspectives on research from direct priming. *J. Clin. Exp. Neuropsychol.* 8: 727–743.
Schacter DL, Reiman E, Uecker A, Polster MR, Yun LS, and Cooper LA (1995) Brain regions associated with retrieval of structurally coherent visual information. *Nature* 376: 587–590.
Schacter DL, Savage CR, Alpert NM, Rauch SL, and Albert MS (1996) The role of hippocampus and frontal cortex in age-related memory changes: A PET study. *Neuroreport* 7: 1165–1169.
Schacter DL, Wig GS, and Stevens WD (2007) Reductions in cortical activity during priming. *Curr. Opin. Neurobiol.* 17: 171–176.
Schnyer DM, Dobbins IG, Nicholls L, Davis S, Verfaellie M, and Schacter DL (in press) Item to decision mapping in rapid response learning. *Mem Cognit.*
Schnyer DM, Dobbins IG, Nicholls L, Schacter DL, and Verfaellie M (2006) Rapid response learning in amnesia: Delineating associative learning components in repetition priming. *Neuropsychologia* 44: 140–149.
Schott BJ, Henson RN, Richardson-Klavehn A, et al. (2005) Redefining implicit and explicit memory: The functional neuroanatomy of priming, remembering, and control of retrieval. *Proc. Natl. Acad. Sci. USA* 102: 1257–1262.
Schott BJ, Richardson-Klavehn A, Henson RN, Becker C, Heinze HJ, and Duzel E (2006) Neuroanatomical dissociation of encoding processes related to priming and explicit memory. *J. Neurosci.* 26: 792–800.
Shmuel A, Augath M, Oeltermann A, and Logothetis NK (2006) Negative functional MRI response correlates with decreases

in neuronal activity in monkey visual area V1. *Nat. Neurosci.* 9: 569–577.
Simons JS, Koutstaal W, Prince S, Wagner AD, and Schacter DL (2003) Neural mechanisms of visual object priming: Evidence for perceptual and semantic distinctions in fusiform cortex. *Neuroimage* 19: 613–626.
Slotnick SD and Schacter DL (2004) A sensory signature that distinguishes true from false memories. *Nat. Neurosci.* 7: 664–672.
Squire LR, Ojemann JG, Miezin FM, Petersen SE, Videen TO, and Raichle ME (1992) Activation of the hippocampus in normal humans: A functional anatomical study of memory. *Proc. Natl. Acad. Sci. USA* 89: 1837–1841.
Soldan A, Mangels JA, and Cooper LA (2006) Evaluating models of object-decision priming: Evidence from event-related potential repetition effects. *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 230–248.
Stevens WD and Grady CL (2007) Insight into frontal lobe function from functional neuroimaging studies of episodic memory. In: Miller BL and Cummings JL (eds.) *The Human Frontal Lobes: Functions and Disorders,* 2nd edn., pp. 207–226. New York: Guildford.
Tenpenny PL (1995) Abstractionist versus episodic theories of repetition priming and word identification. *Psychon. Bull. Rev.* 2: 339–363.
Thapar A and Rouder JN (2001) Bias in conceptual priming. *Psychon. Bull. Rev.* 8: 791–797.
Thiel A, Haupt WF, Habedank B, et al. (2005) Neuroimaging-guided rTMS of the left inferior frontal gyrus interferes with repetition priming. *Neuroimage* 25: 815–823.
Tipper SP (1985) The negative priming effect: Inhibitory priming by ignored objects. *Q. J. Exp. Psychol. A* 37: 571–590.
Tulving E and Schacter DL (1990) Priming and human memory systems. *Science* 247: 301–306.
Turk-Browne NB, Yi DJ, and Chun MM (2006) Linking implicit and explicit memory: Common encoding factors and shared representations. *Neuron* 49: 917–927.
Vogels R, Sary G, and Orban GA (1995) How task-related are the responses of inferior temporal neurons? *Vis. Neurosci.* 12: 207–214.
Voss JL and Paller KA (2006) Fluent conceptual processing and explicit memory for faces are electrophysiologically distinct. *J. Neurosci.* 26: 926–933.
Vuilleumier P, Henson RN, Driver J, and Dolan RJ (2002) Multiple levels of visual object constancy revealed by event-related fMRI of repetition priming. *Nat. Neurosci.* 5: 491–499.
Vuilleumier P, Schwartz S, Duhoux S, Dolan RJ, and Driver J (2005) Selective attention modulates neural substrates of repetition priming and ''implicit'' visual memory: Suppressions and enhancements revealed by fMRI. *J. Cogn. Neurosci.* 17: 1245–1260.
Wagner AD, Desmond JE, Demb JB, Glover GH, and Gabrieli JDE (1997) Semantic repetition priming for verbal and pictorial knowledge: A functional MRI study of left inferior prefrontal cortex. *J. Cogn. Neurosci.* 9: 714–726.
Wagner AD, Maril A, and Schacter DL (2000) Interactions between forms of memory: When priming hinders new learning. *J. Cogn. Neurosci.* 12: 52–60.
Wagner AD, Schacter DL, Rotte M, et al. (1998) Building memories: Remembering and forgetting of verbal experiences as predicted by brain activity. *Science* 281: 1188–1191.
Wheatley T, Weisberg J, Beauchamp MS, and Martin A (2005) Automatic priming of semantically related words reduces activity in the fusiform gyrus. *J. Cogn. Neurosci.* 17: 1871–1885.
Williams P and Tarr MJ (1997) Structural processing and implicit memory for possible and impossible figures. *J. Exp. Psychol. Learn. Mem. Cogn.* 23: 1344–1361.
Wig GS, Grafton ST, Demos KE, and Kelley WM (2005) Reductions in neural activity underlie behavioral components of repetition priming. *Nat. Neurosci.* 8: 1228–1233.
Wiggs CL and Martin A (1998) Properties and mechanisms of perceptual priming. *Curr. Opin. Neurobiol.* 8: 227–233.
Yi DJ and Chun MM (2005) Attentional modulation of learning-related repetition attenuation effects in human parahippocampal cortex. *J. Neurosci.* 25: 3593–3600.
Yi DJ, Kelley TA, Marois R, and Chun MM (2006) Attentional modulation of repetition attenuation is anatomically dissociable for scenes and faces. *Brain Res.* 1080: 53–62.
Zago L, Fenske MJ, Aminoff E, and Bar M (2005) The rise and fall of priming: How visual exposure shapes cortical representations of objects. *Cereb. Cortex* 15: 1655–1665.
Zeelenberg R, Wagenmakers EJ, and Raaijmakers JG (2002) Priming in implicit memory tasks: Prior study causes enhanced discriminability, not only bias. *J. Exp. Psychol. Gen.* 131: 38–47.
Zubicaray G, McMahon K, Eastburn M, Pringle A, and Lorenz L (2006) Classic identity negative priming involves accessing semantic representations in the left anterior temporal cortex. *Neuroimage* 33: 383–390.

# 2.34 Motor Learning and Memory

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## 2.34.1 Introduction and Definition of the Field

Most of us have marveled at the extreme levels of movement skill shown by champion athletes, musicians and dancers, or artisans. Certainly, we almost take for granted our capabilities to drive a car, type on our computer keyboard, or play golf, as the many skills we seem to possess make life productive at work and enjoyable at play. But the capability for production of actions is far more important and fundamental than this. A moment's reflection will reveal that the capability to move our limbs is an essential aspect of life for, without movement capabilities, we could not feed ourselves, locomote to find food or shelter, or, for that matter, even reproduce or survive after birth. Viewed in this way, the capability to move purposefully and efficiently is a critical aspect of life itself, and its study requires little justification.

The study of movement capabilities is very broad, spanning many levels of analysis and touching many different fields or departments within the typical university. Researchers frequently study these phenomena by focusing on such varied levels of analysis as the biochemical changes with muscle contractions or brain activity, the neural underpinnings of actions, the biomechanics of skilled activities, the learning of new actions, the changes in movement with age, and even the role of movements for societies (migrations or wars). For our purposes here, we narrow the focus to areas of study that are closely related to experimental psychology where, as with other areas within psychology, the concern is with observable behavior in individuals (mainly humans) and for the understanding of how this behavior is organized and produced. This focus has, in the past few decades, been called various names such as kinesiology, motor neuroscience, human performance, or motor control. This field is defined by the scientific study of movements by humans and animals, with attempts to understand the actions' characteristics and fundamental underpinnings and ultimately organizing the many variables' experimental effects into testable theory.

A part of the field of motor control has, since the earliest days of experimental psychology, been the focus on how skills are learned with practice and experience. The study of learning in general has always been a core focus for experimental psychology and, as we discuss later, the study of skill learning has undergone many changes in popularity over the years as well. The label motor learning is the one most often associated with the field directed at understanding the acquisition of skill (or movement capability) with practice or experience. This chapter focuses on this area directly.

## 2.34.2 Motor Learning: Acquisition of Procedural Knowledge

It is useful to make an important distinction about the kind of knowledge that is the product of motor learning, as it helps to set the field of motor learning apart from the larger field of human learning as it is studied in experimental psychology. Roughly speaking, knowledge can be thought of in two ways (or perhaps, as two ends of a continuum). Declarative knowledge is the capability to know that, as in knowing that the first American president was George Washington, or that $2+2=4$. A distinctly different kind of knowledge is procedural knowledge, which is the capability to know how to. . ., as in knowing how to ride a bicycle, how to type on a keyboard, or how to use a machine tool.

We suggest that, for the much of research efforts concerning human and animal learning in experimental psychology, the laboratory subject is acquiring declarative knowledge. For example, in verbal learning, the participant already knows how to say the proper answer or press the correct response key; what is learned is the selection of an existing behavior out of a large number of existing behaviors. In animal learning, the animal may learn to press the bar in the cage after some stimulus information is presented; learning how to press the bar is not of much interest. Also, learning to run a maze seems to be, at first glance, a highly motor activity; but running and learning to turn corners are not what is learned in the experiment – rather when and which way to turn are the critical issues.

For motor learning, on the other hand, the problem for the learner is how to produce a particular action, e.g., a dislocate-shoot-handstand on the still rings; the choice of which action to do is not the issue, as it is clear that this particular action is the goal. Now, the problem for the learner is to develop a way to control the musculature and limbs so that the designated action can be performed. Thus, motor learning does not seem to involve learning which previously acquired action to make, but rather it involves how to produce a given action. This is emphasized in motor-learning experiments, where tasks for which subjects have not had any previous experience are typically used (see Schmidt and Lee, 2005: Chapter 2).

We can probably think of counter-examples for animal learning. One might be the circus bear who has learned to ride a bicycle, or the dog who rides a surfboard, behaviors that are almost certainly not genetically acquired and must have been learned. If these kinds of behaviors were studied in animal-learning laboratories, we would be forced to call the product of this practice motor learning. But tasks like this are rarely studied in the laboratory, where the preferred method seems to be to use already acquired actions (e.g., bar presses) so that what is learned is when, or under what conditions, to press the bar – declarative knowledge. Even with these possible exceptions, the declarative/procedural distinction seems to be the chief factor that separates the field of motor learning from many other forms of learning examined in the laboratory. How procedural knowledge is acquired with practice is the defining feature of motor-learning research.

## 2.34.3 Brief Historical Background of Motor Learning Research

Historians owe a debt of gratitude to the work of McGeoch (1927, 1929, 1931), Irion (McGeoch and Irion, 1952; Irion, 1966), and Adams (1987), who provided detailed reviews of motor learning research during the past century. Like those reviews, the present chapter does not detail closely related areas of research such as the neurophysiology of motor control, or human factors and ergonomics research. Rather, we focus on studies of motor behavior, and how the permanent capability to achieve a goal-oriented action improves as the direct result of practice – the study of motor learning.

Early experimental investigations of motor learning were concerned with real-world skills, and the problems associated with their acquisition, retention, and transfer. For example, Bryan and Harter (1897, 1899) studied telegraphy (sending and receiving Morse code), documenting the changes that occur with improvements in skill (see also Taylor, 1911/1967). The acquisition (Book, 1908/1925) and retention (Hill et al., 1913; Hill, 1934, 1957) of typewriting skills represented another focus of study of learning real skills.

The initial stage or period of skill acquisition provided important information about the motor learning process, which was unavailable to the experimenter if the participant had already acquired some skill in the task to be learned. So, similar to the use of nonsense syllables as the unit of study in verbal memory experiments, psychologists created new tasks to examine how learning proceeded in the absence of previously acquired skill. Very simple tasks such as blindfolded line-drawing (Thorndike, 1927; Elwell and Grindley, 1938) and more complex tasks such as mirror tracing (Snoddy, 1926) and pursuit tracking (Koerth, 1922) were frequently used motor learning tasks.

The use of novel motor tasks also facilitated the study of various practice variables, as these variables were believed to have their most significant impact during the early stage(s) of skill acquisition. During the first half of the twentieth century, the most commonly studied motor learning variables included the effects of practice distribution (Bourne and Archer, 1956) and knowledge of results, or KR (Thorndike, 1927; MacPherson et al., 1948, 1949; Dees and Grindley, 1951). Like all behavioral science disciplines, certain topics in motor learning have gone through periods of intense scrutiny, during which considerable research was conducted and their results archived. Much of this work was driven by theories that, at the time, generated a great deal of interest. A good example in early motor learning research was the study of distribution of practice. A large volume of research was produced during the 1940s and 1950s concerning the effects of rest period durations between work periods, almost always using continuous tasks (such as pursuit tracking or mirror tracing). Much of this work was conducted with the purpose of testing the tenets of Hull's (1943) theory of habit strength and drive reduction. Practice distribution using continuous motor skills was viewed as a good behavioral vehicle to study Hull's theory in humans. So, when interest in Hull's theory waned, so too did experiments on practice distribution in motor learning (Adams, 1987; for a review of this work see Lee and Genovese, 1988). The study of KR suffered a similar fate. Augmented feedback, such as KR, was important to theorists who studied conditioning as a means to shape behavior.

The cognitive psychology revolution in the 1950s and 1960s ended most of the motor learning research undertaken in psychology departments. The new hot topics were memory and attention. By the 1970s, research output in the study of learning, such as paired associate learning and motor skills learning, was significantly reduced. Disinterest in motor-learning research continued in psychology departments through the end of the century and largely remains so today (Rosenbaum, 2005). However, motor learning research has become revitalized since the 1970s due mainly to four key factors.

## 2.34.4 Four Factors Contributing to the Modern Era of Motor Learning Research

### 2.34.4.1 Technology

By the early 1980s, researchers had generally become dissatisfied with simple measures of performance, such as reaction time or unidirectional error scores. Everyday actions involve complex movements, usually requiring the coordination of multiple degrees of freedom. The rapid advancements in computers and digital technology in the latter part of the century gave rise to more sophisticated methods to examine complex movements and the ability to record and analyze much more data than had previously been possible. Digital recording devices allowed the simultaneous recording of multiple actions and computers enabled the power and flexibility to put them to work. The elegance of motor control could now be studied in detail, and relatively cheaply and easily so.

### 2.34.4.2 Relevance to Other Disciplines

A second factor that gave rise to the rebirth of motor learning research was the expansion of interest to other disciplines. Motor learning had always been relevant to physical educators who studied sport skills, and this interest continued to grow as technology facilitated the examination of specific sport skills in experiments (Williams and Hodges, 2004). Motor learning also grew as an area of research interest to scientists in other disciplines. Specialists in human factors and ergonomics found motor learning to be a fruitful area for understanding the learning process in occupation-related settings (e.g., Agruss et al., 2004). Various health-related disciplines discovered important relationships between motor learning and factors of direct relevance to them, such as stroke rehabilitation in physical therapy (Boyd and Winstein, 2003; Krakauer, 2006), voice rehabilitation (Verdolini and Lee, 2004; Yiu et al., 2005), and the acquisition of chiropractic (Descarreaux et al., 2006), dental (Wierinck et al., 2006), and surgical skills (Dubrowski et al., 2005; Brydges et al., 2007).

### 2.34.4.3 Two Important Papers

Although interest in motor skills research among psychologists waned, the role of psychological and cognitive processes as key components of the motor learning process became a motivating factor for renewed interest, and this interest can be localized to the publication of two important papers. The papers were important because they reported findings that were counterintuitive to popular thinking at the time. Shea and Morgan (1979) reported the findings of two groups of subjects who practiced three versions of a task that required subjects to learn patterns of arm movements and to perform them as rapidly as possible. A blocked group practiced the patterns in a drill-type order, which minimized the interference that practice of one task could exert on another task; all trials on one pattern were completed before trials began on a new pattern. Performance of this blocked group was very good: They achieved an asymptote level of reaction time and movement time

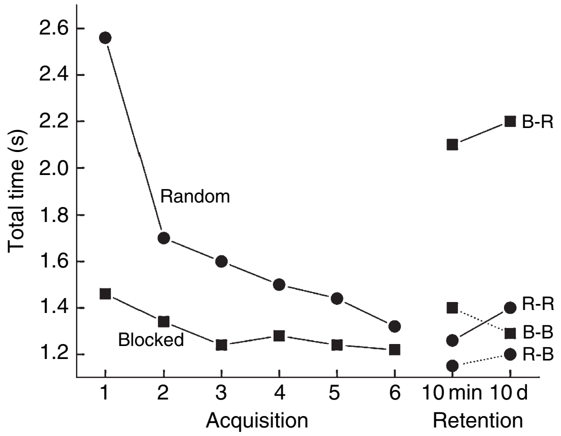


**Figure 1** Blocked practice produces better performance during the acquisition trials than random practice. However, the random group performs better than the blocked group in immediate (10-min) and delayed (10-day) retention tests, regardless of how the retention tests are ordered (e.g., R–B = performance of the random group in blocked-ordered retention tests). Data from Shea JB and Morgan RL (1979) Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *J. Exp. Psychol. Hum. Learn. Mem.* 5: 179–187.

very quickly (presented as total time in **Figure 1**). In contrast, performance of the random group, which never received practice trials on the same pattern more than twice in a row, was poor, never reached asymptote, and generally was worse than the blocked group throughout acquisition. These findings were consistent with well-known principles of the effects on interference on performance: Less interference produced better performance and vice versa.

The counterintuitive nature of Shea and Morgan's findings were revealed in retention and transfer tests conducted after delays of 10 min and 10 days. In these tests (conducted in both random and blocked orders), performance of the random group was superior to that of the blocked group on the blocked-ordered retention tests (compare the R-B and B-B symbols in **Figure 1**). And the effects of random practice were far superior in the randomly ordered retention tests (compare the R-R and B-R symbols in **Figure 1**). Apparently, the very same interference effects that resulted in performance deficits in acquisition also resulted in learning benefits as revealed in the retention tests. This finding was called the contextual interference effect (cf. Battig, 1979; Battig and Shea, 1980) and remains a topic of continued interest today (see the section titled 'Contextual interference').

The other important paper, published around the same time, was a review of the extant literature regarding the effects of KR in motor learning (Salmoni et al., 1984). The message delivered in this review paper was consistent in many respects to the message of the Shea and Morgan (1979) paper. Specifically, if one were to make an assessment about the efficacy of learning variables on the basis of performance during an acquisition session (i.e., when the manipulations were ongoing), then a very different conclusion would emerge compared to an assessment that was based on performance in a retention or transfer test (i.e., when the conditions of performance are equated). In their review of the KR literature, Salmoni et al. reported several instances in which the effects of a KR variable in acquisition were reversed in a retention or transfer test. Similar to the Shea and Morgan findings, these conclusions highlighted the important distinction between performance and learning and caused researchers to reassess their thinking about the factors and theoretical issues underlying the learning of motor skills.

We discuss these research areas in detail later. However, it is interesting to note that much of the interest in motor learning for researchers in other disciplines grew directly out of the counterintuitive nature of the findings reported in the new studies of contextual interference and KR effects. For some, it was the relative ineffectiveness of practice regimes in these specific, applied research areas that motivated this interest in motor learning research (e.g., Dubrowski et al., 2005).

#### 2.34.4.4 Theory

The last factor that has spirited the growth of motor learning research concerns the product of skill acquisition – memory for motor skill – which is the domain of motor control. Perhaps this factor, more than any other, has resulted in the growth of motor learning from a theoretical perspective. Movement is the result of neural mechanisms that interact to result in action. At any one time, the true capability for motor skill is a concatenation of the current state of these interactions in memory, which is the direct result of practice. Two formalized theories of motor control, published in the 1970s, provided a strong rationale regarding how motor control is represented in memory. We begin by reviewing these theories and how they influenced motor learning research.

## 2.34.5 Motor Control: The Memory (Product) of Motor Learning

Over the years, there have been many separate statements or suggestions concerning what is learned in motor learning, that is, what is the product of practice? Two of these more formalized attempts are described next.

### 2.34.5.1 Adams's Theory

In the late 1960s, Jack Adams emphasized that learning could be conceptualized in terms of feedback-based, closed-loop processes, both for verbal learning (Adams and Bray, 1970) and motor learning (Adams, 1971). His motor-learning theory was based on the large body of empirical literature that used slow, self-paced, linear-positioning tasks, with the numerous practice variables that had been studied in this way. For these skills, the learner's task was to move a lever (or other manipulandum) to a particular goal location, and practice with KR was typically used.

For Adams, practice created what he called the perceptual trace – a memory structure that was the product of learning. After each attempt at positioning the lever, the subject receives KR about his or her error, which provides a basis for a more correct action on the next trial, and so on. Thus, for Adams, the function of KR was to guide the action toward the target over trials. Experience at the target location generated movement-produced (chiefly kinesthetic) feedback about that position, which was stored as a perceptual trace. With repeated trials increasingly near the target position, the most frequently experienced perceptual trace came to represent the sensory qualities of being at the target location. The process of reinforcing an increasingly narrow range of perceptual traces near the correct trace is illustrated in the three panels in **Figure 2**. Once this perceptual trace was sufficiently strong, on a subsequent attempt the subject would move to a position such that the difference (error) between his or her actual feedback at the moment and the acquired perceptual trace was minimal, using closed-loop processes. Thus, variations of KR that produced a faster approach to the target, or more accuracy at the target, were thought to be beneficial for learning because they made the perceptual trace more distinctive or reliable. This process also improved the subject's capability to detect his or her own errors (the difference between concurrent sensory feedback and the perceptual

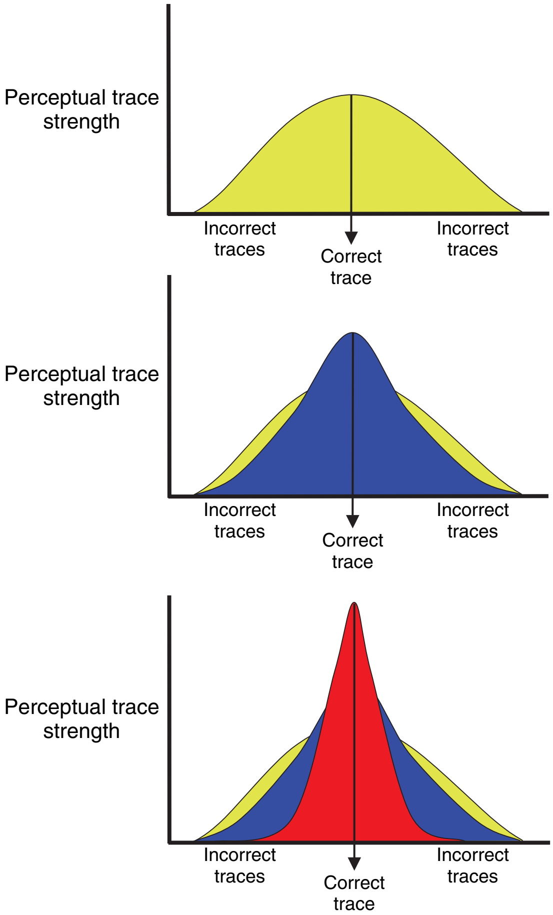


**Figure 2** A conceptualization of Adams's (1971) theory. As repetitions accumulate, the representation strength of the correct perceptual trace becomes more fine-tuned in memory. With many repetitions, the correct perceptual trace becomes the dominant modal representation.

trace). In this manner, a strong perceptual trace would facilitate continued learning in the absence of external KR from the experimenter.

Adams's theory had a powerful effect on the field, generating considerable empirical activity in providing tests of the various predictions. As a result of this activity, research identified a number of shortcomings in the theory.

#### *2.34.5.1.1 No open-loop processes*

Adams intended his theory to be an account of slow, linear positioning tasks, and he made no attempt to explain the control of rapid actions. For rapid tasks, such as throwing, striking, or other brief movements of the limbs, evidence has mounted showing that feedback acts too slowly for it to be the basis for movement control. Alternatively, centrally generated, open-loop processes were proposed that were presumably responsible for producing such fast actions without requiring movement-produced feedback (Henry and Rogers, 1960; Keele, 1968). These open-loop processes have been described under the general heading of motor programs, about which we will provide additional discussion later. But, in short, the inability for Adams's theory to account for rapid actions was taken as a limitation.

#### *2.34.5.1.2 Novelty*

One logical problem with the theory was the inability to account for novel actions: Actions that the subject had never produced previously. If the basis for the perceptual trace was experience with the correct action, then how could the person ever make a variation of a skill that he or she had never practiced before, such as positioning a weighted limb in a new location? Perceptual traces, in this view, were limited to the actions that had actually been performed or practiced previously. A further implication is that, in order to perform the many varieties of actions that we do, we must have a very large number of perceptual traces in memory. This naturally brought up the concern regarding how the central nervous system could store and retrieve all of the traces necessary to allow us to move with the ease and efficiency that we can.

#### *2.34.5.1.3 Generality*

Another concern was the fact that skills seemed to demonstrate a particular kind of generality. That is, when we throw, we can throw in a very large number of ways, many of which have not been experienced before. It is as if the skill of throwing, for example, could be generalized to a wide number of similar but nonidentical throwing actions. Adams's theory did not provide a way for this kind of generalization to occur.

### 2.34.5.2 Schema Theory

Schema theory, proposed by Schmidt (1975), grew out of the several drawbacks to Adams's theory. In particular, the concern was to provide an account of learning in rapid as well as slower actions, to provide a way for novel actions to be performed, and to account for the generality that seemed to be shown in so-called classes of actions (such as throwing). As with Adams's theory, the concern was for discrete actions only, as other kinds of processes seem to operate in continuous tasks (e.g., swimming, steering a car).

#### 2.34.5.2.1 Open-loop processes

Schmidt proposed that discrete actions such as overarm throwing are really a collection of actions that fall into the same class. Each member of the class is different in nearly countless ways (e.g., speed, trajectory, object size, throwing distance), but each member of the class had certain features that were invariant (Schmidt, 1985) across the members of the class. The idea was that this class of actions was governed by what was termed a generalized motor program (GMP), which had certain invariant features structured rigidly in it. The debate about what these invariant features are, and whether they are sufficiently invariant, has raged for several decades.

Chief among these invariants are sequencing and relative timing. Sequencing of the parts of an action simply refers to the order in which various events occur: For example, activity in Muscle 1 precedes Muscle 2, and both precede Muscle 3. It was assumed that all members of a class of actions have the same sequencing of elements. Relative timing refers to the temporal structure, or temporal pattern, of the action. If various muscle contractions were recorded, then we would see a temporal regularity in these elements. Specifically, for an action with several muscles participating, relative timing is invariant if the ratios among the contraction durations are constant across changes in, say, the overall duration of the action. Also, invariance requires that the duration of any contraction divided by the overall duration of the action must be constant across changes in overall duration. Another feature of the class of actions is relative force. Relative force refers to the patterning of forces among the various muscles: Muscle 1 always contracts with twice the force as Muscle 2, etc. This is another invariant feature structured in the GMP for the action.

According to the theory, when the performer attempts an action in the class, he or she retrieves the GMP for that class and then adds parameters to the program to suit the particular environmental demands. These parameters are proposed to be the overall duration of the action (throwing rapidly or slowly), the overall amplitude of the action (as in writing one's signature in different sizes), and the particular limbs to be used (writing with the fingers on a check, or with the arm/shoulder ten times larger on a blackboard). The selection of the parameters occurs prior to the action, and the GMP is initiated so that the invariant features of the movement emerge but with different surface features (such as amplitude or speed). Note that this kind of model helps to solve the problem of novelty, mentioned earlier, as a novel set of parameters will produce an action that the performer has never produced before. Also because there is only one program needed for the class, this eliminates the need to have a separate program for every different way that the action can be produced, and helps to solve the problem of storage. Note however, that the theory assumes the existence of the GMPs and is silent about how the programs are learned. This latter question remains one of the largest challenges facing schema theory (Shea and Wulf, 2005).

The theory does, however, provide a way for the parameter-selection process to be learned. When the performer produces an action such as throwing, he or she stores information from four sources: (1) the initial conditions (e.g., the required distance to throw, the weight of the object to be thrown, etc.), (2) the parameters that were used (absolute amounts of force, time, etc.), (3) the outcome in terms of the environmental (e.g., distance thrown) as provided by KR, and (4) the sensory consequences of the movement (how it looked, felt, sounded, etc.). This information is stored only long enough for the performer to update two schemas – rules or relationships among these stored values. The schemas are continuously updated with new information over many parameterizations for the class of actions.

The two schemas are the recall schema and the recognition schema. The recall schema is the relationship between the past parameters used and the past outcomes of the action, whereas the recognition schema is the relationship between the past sensory consequences of the action and the past outcomes. Given these schemas, when the person wants to produce a particular, perhaps novel, outcome with the action-class, he or she uses the recall schema to select the parameters based on the desired outcome. The recognition schema is used so that the performer can select the expected sensory consequences based on the desired outcome; this forms the basis for recognizing errors in performance after the action is produced. For example, knowing that on this occasion I want to throw 20 m, the recall schema estimates the parameter values needed (based on past experience with this class of tasks but with different outcomes), they are supplied to the GMP, and the action is triggered.

#### 2.34.5.2.2 Fast versus slow actions

Finally, schema theory proposes that rapid actions (e.g., throwing, say 100 ms in duration) and slow actions (e.g., linear positioning, say 3 s in duration) are produced systematically differently. Fast actions are produced by executing the GMP in an open-loop manner. After the action, the performer can compare the actual sensory consequences (response-produced feedback) with the expected sensory consequences from the recognition schema, providing a basis for the performer knowing about errors in movement production.

Slow actions are produced in a way analogous to Adams's (1971) proposal. When a slow action is required, the subject generates the expected sensory consequences from the recognition schema and then moves to that position such that the actual sensory consequences (movement-produced feedback) match the expected sensory consequences; the GMP is not involved. This leaves no capability for the performer to detect postperformance errors, as this error-detection process is used to produce the movement in the first place (see Schmidt and White, 1972). Thus, the overall generalization is that closed-loop processes produce slow actions and open-loop processes produce fast actions. There is considerable evidence supporting the distinction between motor control processes involved in fast and slow actions (see Schmidt and Lee, 2005: Chapter 13).

#### 2.34.5.2.3 Variability-in-practice effects

One interesting implication of schema theory is that variability in practice among members of a class of actions, as compared to an equal amount of practice on any one of them, should be beneficial for learning (i.e., transfer performance on a novel variant). This is so because the schema for the class of actions – analogous to a regression line – is built up more reliably as the learner gains more variability in prior experiences. In this manner, the theory predicts that transfer performance to a novel variant is more accurate because the schema-rule is better defined. This somewhat counterintuitive prediction has been tested many times over the past 25 years, and the evidence generally supports it (McCracken and Stelmach, 1977; Shapiro and Schmidt, 1982; Lee et al., 1985; Van Rossum, 1990; see Schmidt and Lee, 2005: Chapters 11 and 13, for a summary and discussion). Another, even more counterintuitive prediction is that, for a task with, say, five variants (A, B, C, D, and E along some dimension such as speed), practice at A, B, D, and E is more beneficial for transfer to Variant C than is an equal amount of practice at Variant C itself. This prediction was supported in research by Shea and Kohl (1991), which is

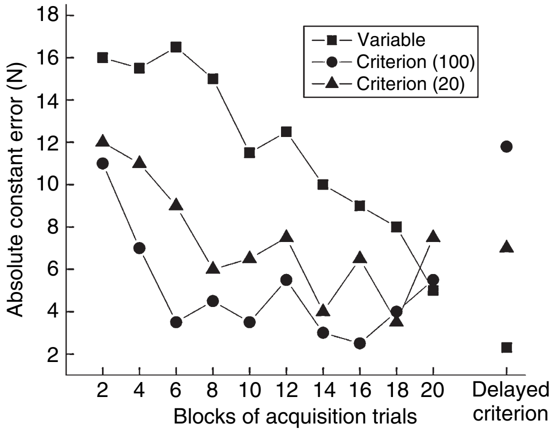


**Figure 3** Variable practice (at goals surrounding and including a criterion target force) produces increased accuracy on a delayed criterion test than equal amounts of criterion-only task performance when controlling both for the number of criterion task trials (Criterion 20 group) and the total number of practice trials (Criterion 100 group). Data from Shea CH and Kohl RM (1991) Composition of practice: Influence on the retention of motor skills. *Res. Q. Exerc. Sport* 62: 187–195.

illustrated in **Figure 3**. In their research, Shea and Kohl asked participants to learn a force-production task, providing them with 100 trials to learn a criterion force of 150 N. The variable practice group received only 20 of these trials at the criterion force, and 80 trials were practiced at goals that were 50 or 100 N above or below the criterion force. Two control groups were included that received either 20 or 100 practice trials 'only' at the criterion force. A delayed retention test at the criterion force revealed that the variable practice group performed with less mean error than both the two criterion-only practice groups, supporting the schema-theory prediction. This variability-in-practice evidence is seen as contradictory to Adams's theory. The findings have strong implications for the structure of real-world practice.

#### 2.34.5.2.4 Learning parameters versus learning programs

In another line of research, investigators have found that movement errors arising from two sources can be separated. Errors stemming from the specification of parameters can be dissociated from errors resulting from the generation of the GMP itself (Wulf et al., 1993). Being able to separate these two kinds of errors makes it possible to study how various practice conditions affect these two theoretical processes. For example, increased relative frequency of KR enhances parameter learning but degrades program learning (Wulf et al., 1993; Wulf and Schmidt, 1996). Several of the dissociations between factors that affect program versus parameter learning have been shown recently, and they tend to support the separation of these two constructs in memory (Wulf and Shea, 2002). Much more needs to be done in this area, in our view.

#### 2.34.5.2.5 Especial skills

Recent findings by Keetch et al. (2005) seem to provide some difficulties for the schema view, however. One prediction arising from schema theory is that practice at any one variant of a class of actions exerts its effect by strengthening the schema for the whole class, not just for that particular variant. Thus, extensive practice at one of these members should not be evident on this particular member, but rather on the class as a whole. Keetch et al. studied set shots (where the feet do not leave the floor) made by skilled basketball players across various shot distances. They found that accuracy at the foul line (15 ft), which has had massive amounts of practice, was far better than predicted by performance at shot distances longer than or shorter than 15 ft (i.e., 9, 11, 13, 17, 19, and 21 ft). This effect can be seen in **Figure 4**. Keetch et al. interpreted these findings in terms of what they called an especial skill – an individual variant of a class of actions that, because it has received massive amounts of practice, stands out from other seemingly similar variants of the same class. These kinds of results suggest that learning is manifested not only in processes of generalization (as suggested by schema theory), but also by specificity in terms of these especial skills. Newer theories of motor learning will have to recognize both types of effects.

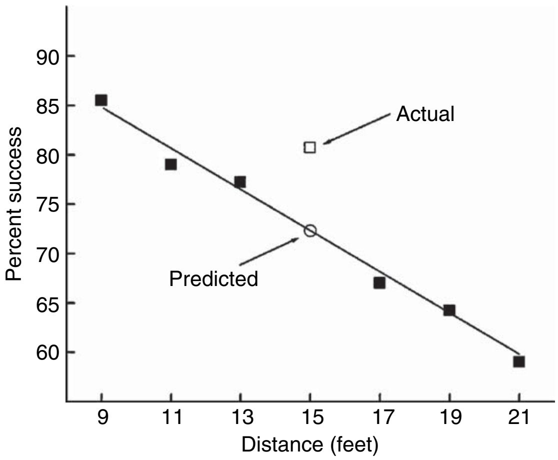


**Figure 4** Shooting accuracy data at the free-throw line (open square symbol) exceeds predicted free-throw performance (unfilled circle symbol) based on set shot data from adjacent locations (filled square symbols). Data from Keetch KM, Schmidt RA, Lee TD, and Young DE (2005) Especial skills: Their emergence with massive amounts of practice. *J. Exp. Psychol. Hum. Percept. Perform.* 31: 970–978.

## 2.34.6 Cognitive Operations During Motor Learning

Motor control, the product in memory about which both Adams (1971) and Schmidt (1975) theorized, was critically dependent upon the interaction of movement and feedback (both sensory and augmented feedback). What was not considered important in these theories, however, was the role that cognitive operations served in the development of motor memories. As we mentioned earlier, it was the prominence of these theories, combined with their failure to explain the effects of cognitive operations during practice, that set the stage for the impact on learning research of the Shea and Morgan (1979) and Salmoni et al. (1984) papers.

### 2.34.6.1 Contextual Interference

The findings by Shea and Morgan (1979) on the effects of blocked and random practice were unexpected, given the views about memory that had been presented by Adams (1971) and Schmidt (1975). There was every reason to expect that blocked practice would be superior to random practice for learning, and this was confirmed by the acquisition data collected during practice. The reversal seen in retention and transfer might have been considered a set of data outliers, if it were not for the plausible theoretical rationale that was proposed to explain the results. Shea and Morgan found an ally in William Battig, and they relied heavily on some of Battig's ideas regarding elaborative and distinctive processing mechanisms to explain their results.

Battig had long been a proponent that learning comes at a cost. Earlier, he had suggested that "intertask facilitation is produced by intratask interference" (Battig, 1966: 227), referring to the finding that the difficulty in acquiring various items within the same category actually facilitated transfer when learning a different category of items. An expanded view (Battig, 1979), which he termed contextual interference, further developed his stance regarding the relationship between interference and facilitation.

#### 2.34.6.1.1 Elaborative and distinctive processing

An important part of Shea and Morgan's explanation for the differences in learning due to random and blocked practice was similar to Battig's (1979) views regarding elaborative and distinctive processing mechanisms. Consider first a typical trial in a blocked practice schedule. The learner prepares to perform one of the tasks to be learned, executes the action when cued to do so, and then evaluates the completed performance on the basis of movement-produced feedback and KR (if provided). By the very nature of blocked practice, the next trial requires essentially that same movement preparation and execution as the previous trial. In contrast, a typical random practice trial requires that the learner prepare, execute, and evaluate performance for a task that has a different goal on consecutive trials. Shea and Morgan (1979) proposed that the operations completed for one task, in the context of operations that may still reside in memory for a different task, provide more comparative and contrastive information about the tasks to be learned, compared to a blocked practice schedule.

In Shea and Morgan's view, the comparative and contrastive information during random practice would be explicit and verbalizable, and therefore should be available to report. This prediction was supported in a subsequent study by Shea and Zimny (1988), who found that subjects in a random-practice condition were more likely than those in blocked practice to provide information about the just-completed task in ways that set the task apart from the other tasks to be learned. Such information was argued to have made the explicit recall of the tasks more memorable, thus facilitating performance in retention tests.

The views of Shea and Morgan (1979) also suggest that any practice schedule (not necessarily a random schedule) that promotes comparative and contrastive processing should facilitate learning compared to a blocked schedule. A study by Wright (1991) provided strong support for this argument by combining different between-trial processing activities with a blocked practice schedule. One group of subjects was asked to describe the task that had just been performed, while another group was asked to describe a different task. A third group rested during the interval, and a fourth group was asked to explicitly describe the differences in task demands for the just-performed trials compared to one of the other tasks to-be-learned. The explicit processing of this latter group resulted in retention that was far superior to that of the other three groups, even though all groups had physically performed the tasks in a blocked schedule. The findings supported the proposition that random practice places more demands on the learner to prepare and evaluate performance in a manner that makes the information that has been learned about each of the tasks more memorable and distinctive.

#### 2.34.6.1.2 Action reconstruction processing

An alternative view of the random/blocked effects emerged from research performed by Lee and Magill (1983). In their view, the differences between random and blocked practice schedules were similar to the effects seen in verbal memory when item repetitions are spaced during study, which has the effect of increasing performance in a retention test. According to Jacoby (1978; Cuddy and Jacoby, 1982), the spacing effect results from processing a repetition when the memory for the initial presentation has been forgotten (or at least degraded). Lee and Magill (1983, 1985) modified Jacoby's rationale to explain the contextual-interference effect. The processing requirements to learn a motor skill in a blocked-practice schedule are minimized because all repetitions of the task follow immediately after having just performed the same task. Processes associated with movement planning, execution, and evaluation all concern the very same goal-oriented action. Therefore, these processes need not be fully undertaken on each subsequent trial because the previous plan remains in memory. In contrast, a repetition of any single task in a random schedule may not occur until several trials later, during which the learner is required to abandon any previously constructed action plans in favor of an action plan that is appropriate for the current task demands. When a repetition of that earlier task is again required, the previously constructed action plan for that task is no longer in memory, thereby requiring that the learner reconstruct the action plans anew. It is practice at (re)constructing the action that gives random practice its benefits, according to this view.

Note that these processing requirements for random practice should be undermined if the action planning activities are obviated at the time that a repetition is performed. Such a prediction was tested by Lee et al. (1997) in which modeled augmented information about the temporal components of a timing task was presented to the learner prior to each random practice trial. The powerful advantage of the modeled timing information was clearly evident in the acquisition trial blocks: This random group performed as well as the blocked group throughout acquisition, and both were better than a random group that did not have the modeled timing information. However, the fate of this random group that received modeled information during practice was revealed in learning tests. Despite having received random practice, the modeled information resulted in retention and transfer performance that was as poor as blocked practice, and was much worse than the random group that did not receive the modeled information. In terms of the reconstruction view, these data provided evidence that external reinstatement or augmentation of the action-plan information prior to a practice trial facilitates performance and is detrimental to learning, likely because it eliminates (or at least reduces) the need for the learner to practice the reconstruction of the action by him- or herself.

The findings of Lee et al. (1997) were replicated and extended in an experiment by Simon and Bjork (2002). In their study, groups of blocked and random subjects received modeled information that either matched the task to be performed or was appropriate for the timing requirements of one of the other tasks (mismatched). Their results appear in **Figure 5** and are straightforward. Matched timing models facilitated performance of both blocked and random practice groups (the filled symbols in **Figure 5**), relative to mismatched models (the unfilled symbols). Retention performance, however, benefited from the mismatched models, regardless of the physical order in which the practice trials were undertaken.

Note that the Simon and Bjork (2002) data do not distinguish between the elaboration and reconstruction views of contextual interference. Although the matching models may have provided important planning information that undermined learning, the information from the mismatching models could also have provided contrastive information that benefited both the random and blocked practice groups. Similarly, other studies reveal that processing activities are elevated in random practice relative to blocked, although these findings could be accounted for by either an elaboration or a reconstruction account. For instance, Immink and Wright (1998) showed that preparation times taken prior to action are longer in random than in blocked practice schedules. As well, secondary tasks that are inserted into the interval during which a learner would be planning for an upcoming actions revealed longer probe reaction times for random than for blocked practice (Li and Wright, 2000). These data suggest that planning operations are likely to be elevated during random practice, although these could be result of enhanced elaboration or reconstruction processes.

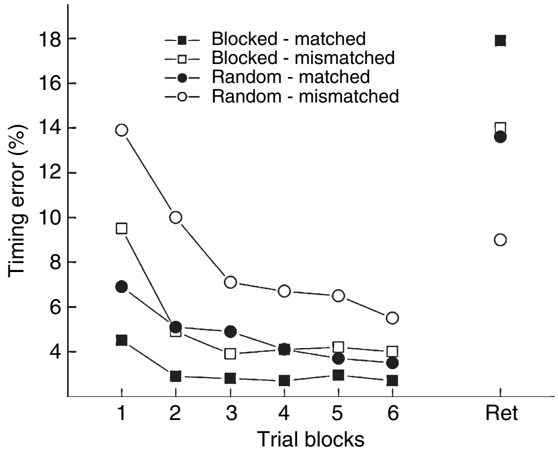


**Figure 5** Matched timing models facilitate acquisition performance (relative timing error from target), but mismatched timing models facilitate retention performance, for both blocked and random groups. Data from Simon DA and Bjork RA (2002) Models of performance in learning multisegment movement tasks: Consequences for acquisition, retention, and judgments of learning. *J. Exp. Psychol. Appl.* 8: 222–232.

More recent studies have identified more precisely what types of processing activities are likely to be affected by random and blocked practice schedules. Specifically, these studies have been designed to tease apart the nature of motor programming activities that have been undertaken in random and blocked schedules. In one experimental manipulation, Immink and Wright (2001) examined motor-programming operations using Morse code responses (dit and dah) within the experimental paradigm developed by Klapp (1996). According to Klapp, two programming operations are involved for this task: (a) organizing the internal components of motor program “chunks,” and (b) sequencing the chunks. Further, it was argued that the internal process can be preprogrammed in advance, especially so if repeated trials on the same task are performed. In their experiments, Immink and Wright (2001) found that random practice facilitated the learning of the internal programming process (relative to blocked practice), but not the sequencing process. They argued that, since the internal process can be preprogrammed, blocked practice required no practice at reconstructive processing, which degraded learning relative to random practice, as measured in retention tests.

An alternative view of the motor-programming process that is influenced by the effects of random and blocked practice was examined in an experiment by Lee et al. (1992). In this study, the nature of the reconstruction process was examined specifically using tasks that differed in terms of their relative timing structure. The rationale was that a set of tasks that shared the same underlying relative timing is based on a common GMP. Regardless of whether the practice sequence order was blocked or random, no reconstruction of the GMP would be required as long as the task variations that were practiced shared the common relative timing. In contrast, for a set of tasks that each had a distinct relative timing, random-practice schedules would require a new reconstruction of the programming process on each trial, but of course, not for blocked practice. Thus, based on reconstructive programming, the authors predicted, and found, large random-blocked differences for a set of different relative timing tasks, but no differences for tasks that shared a common relative timing (see also Magill and Hall, 1990). Although these findings supported the action-reconstruction view, other data suggest that task variations involving same GMPs can also result in a contextual interference effect (Sekiya et al., 1994; Hall and Magill, 1995; Sekiya et al., 1996). These latter findings suggest that simply reconstructing the parameterization of the GMP (same relative timing, but different overall duration) is sufficient to produce random versus blocked differences in learning.

#### *2.34.6.1.3 Cognitive effort*

The effect of task variations in blocked and random practice schedules have also been examined relative to the overall concept of cognitive effort – that random practice is overall, more effortful practice, which works optimally for tasks that are simple and which leads to boredom during practice (Guadagnoli and Lee, 2004). Tasks that are inherently more interesting, or perhaps more complex in nature, should be less amenable to contextual-interference effects because blocked practice engages the learner in more cognitive effort than would be the case for simple tasks. These predictions were supported in research by Albaret and Thon (1998), who found large contextual-interference effects for two simple versions of an arm-movement task, but no differences for the most complex task. Indeed, Wulf and Shea (2002) have suggested that contextual-interference effects are sometimes reversed for very complex tasks, and blocked practice can facilitate learning more than random practice. These suggestions are controversial, however, as large random-practice advantages have been found for complex tasks such as baseball batting (Hall et al., 1994) and handwriting skills in young children (Ste-Marie et al., 2004).

#### *2.34.6.1.4 Meta-memory misattributions*

We mentioned earlier that some of the attraction to this area of research might be attributed to the often-misunderstood distinction between performance and learning, and the counterintuitive conclusions about learning that resulted from these experiments. Two recent lines of research have continued to explore this issue directly. In one experiment, Simon and Bjork (2001) examined the effects of random and blocked practice on actual levels of performance and retention and contrasted these results with the participants' predicted levels of performance and retention. **Figure 6** illustrates their findings. The left panel reveals typical random/blocked effects in acquisition and retention. The right panel illustrates what the learners had predicted would be their level of performance. The findings are clear;

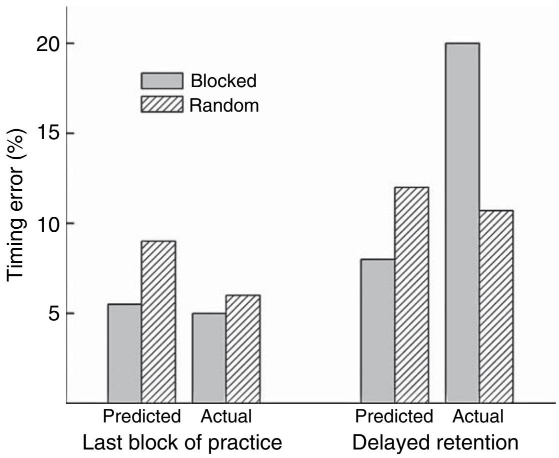


**Figure 6** Blocked and random groups accurately predicted timing error performance at the end of acquisition. In retention, the blocked groups overestimated performance and the random group underestimated performance. Data from Simon DA and Bjork RA (2001) Metacognition in motor learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 907–912.

most importantly, the subjects in the blocked group overestimated their retention performance while the subjects in the random group underestimated retention.

These findings on self-estimations of learning are difficult to reconcile with recent research concerning the self-determination of practice schedules. Almost all studies of practice schedules in the modern era of motor learning research have investigated experimenter-determined schedules, in which the order of practice trials is beyond the learner's control. One would suspect, given the Simon and Bjork (2001) results, that learners would feel more confident with their progress in learning under a blocked schedule and would therefore self-select a schedule of practice that undermines their potential for learning. Surprisingly, such is not the case. New research is emerging (e.g., Keetch and Lee, in press), which suggests that self-determined schedules facilitate learning (relative to yoked controls), regardless of the degree to which the self-selected order is blocked or randomized. This finding might suggest that individual difference variables, in addition to the trial order, combine to influence the effectiveness of practice. We see this new paradigm on practice schedules as a having considerable potential in future motor-learning research.

### 2.34.6.2 Knowledge of Results

The role of knowledge results (KR) in the theories of Adams (1971) and Schmidt (1975) was rather mechanistic: KR served to guide the learner toward making correct movements, and these movements served to strengthen either the correct perceptual trace (in Adams's theory) or the schemas (in Schmidt's theory). This view was termed the guidance role by Salmoni et al. (1984) because KR served as a tool that guided the learner toward the target goal and therefore facilitated learning. However, in their reanalysis of the KR literature, Salmoni et al. discovered that the beneficial role of guidance could only be found in experiments when performance during acquisition trials was considered, i.e., during those trials in which the KR manipulation was ongoing. However, the effects on retention of these same variables were rather different. Salmoni et al. found a number of instances in which a KR variable that guided the learner to strong performance during acquisition was actually detrimental to learning as measured in retention. The conclusion that the guidance function of KR played a detrimental role in learning initiated a new round of research that continues today. Importantly, the guidance role of KR highlighted some cognitive factors that intervene during motor learning, which will be discussed in more detail later. First, we describe two KR variables that illustrate both the positive and negative roles for the guidance function of KR.

#### *2.34.6.2.1 Timing of knowledge results*

One of the most frequently studied variables in this area of motor learning research concerns the timing of the KR delivery following the performance of a task. Because augmented feedback refers to information about performance, it is delivered to the learner either concurrently with ongoing performance or following the completion of a performance. Typically, concurrent delivery of KR occurs when the performance of the task is of sufficiently long duration that perception and utilization of the provided information are possible (say, 0.5 s or longer). For tasks in which the movement duration is less than 0.5 s or so, KR is typically delivered after the completion of the movement. If the KR is not delivered instantaneously upon movement completion, then two variables may intercede; there is a time delay and the opportunity for other activities (e.g., motor, cognitive) to be conducted prior to the delivery of the KR. We highlight some research that documents the effects of the timing of KR.

A study by Schmidt and Wulf (1997) illustrates the guidance effects of concurrent feedback. The movement task was to displace a lever by making flexion and extension arm movements that matched precise spatial and temporal requirements. The overall movement time goal was almost 1 s, providing sufficient time for the learner to use concurrent augmented feedback to perform the task. A video monitor was used to provide one group with concurrent feedback by overlapping a trace of the learner's movement production with a template of the perfect (goal) movement. Discrepancies between the actual and goal movements were explicit from the images presented on the monitor. A second group received an image of the produced movement trace together with the goal trace 3 s after the movement had been completed; the monitor was blank during the movement. Schmidt and Wulf (1997) reported a number of spatial and temporal measures of average performance and performance variability. In general, these measures showed advantages during practice that favored the concurrent augmented feedback group. This general trend was reversed in retention: the removal of KR resulted in drastic declines in performance for the concurrent feedback group, but not so for the delayed KR group.

A similar finding for acquisition and retention has been found when the augmented feedback is not presented concurrently, but rather is presented instantaneously on completion of the movement (Swinnen et al., 1990). These researchers found that a delay of 8 s prior to the delivery of KR improves retention, especially if learners are requested to estimate their feedback during this delay period prior to KR delivery. Thus, simply delaying the KR was sufficient to reduce the negative guidance effects of the instantaneous KR, and the estimation procedure provided an additional boost to the learning effect.

Another method by which the timing of augmented feedback can be manipulated has been termed the trials-delay method (Bilodeau, 1956). By this method, the presentation of KR for any specific trial may be delayed for a time period during which one or more intervening trials of the task are practiced. As illustrated in **Figure 7**, studies of this type (Lavery, 1962; Anderson et al., 2001, 2005) have typically found that the immediate delivery of KR (no trials-delay) resulted in superior acquisition performance compared to a trials-delay condition (e.g., Anderson et al., 2001, 2005, used a two-trials-delay condition). However, no-KR retention tests again support the efficacy for learning of the delayed KR practice conditions; in this case, the trials-delay condition typically produces better retention than the immediate KR conditions.

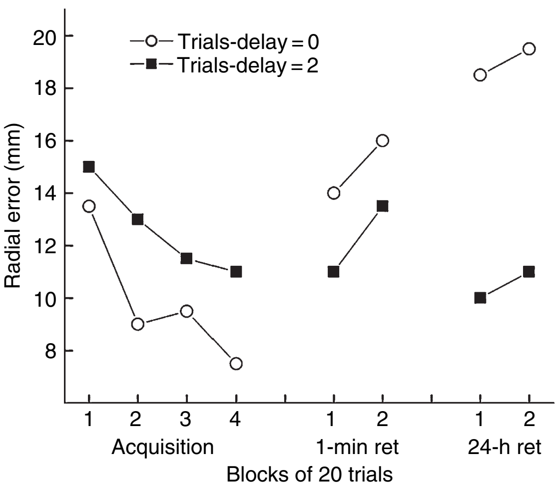


**Figure 7** Immediate delivery of KR produces superior performance in acquisition (error in distance from target) but inferior retention (ret) compared to a KR trials-delay condition. Data from Anderson DI, Magill RA, and Sekiya H (2001) Motor learning as a function of KR schedule and characteristics of task-intrinsic feedback. *J. Mot. Behav.* 33: 59–66.

### 2.34.6.2.2 Frequency of knowledge results

Augmented feedback can also be manipulated by varying the relative frequency of its presentation in relation to the total number of trials practiced. One manipulation is to withhold KR after some trials (reduced relative frequency) and compare the effects in acquisition and retention to a condition that provides KR after every trial (100% relative frequency). The effects of a reduced relative frequency tend to be small, if any, in acquisition. However, retention performance is often enhanced by reduced relative frequency (compared to 100% frequency conditions; e.g., Winstein and Schmidt, 1990).

A variation of the feedback frequency manipulation provides information about every trial, but not directly after every trial. In this manner, the same amount of information is presented but it is done in such a manner that statistically summarizes KR over a series of previous trials. Studies have varied the manner in which summaries are presented: some have used graphs that plot performance for the previous series of trials; other studies have used statistical averages that summarize the average performance tendency for the series of trials. The effects are similar and produce contrasting effects in acquisition and retention, relative to a trial-by-trial KR delivery method. Relative to every-trial KR, summary KR degrades performance in practice but enhances retention (e.g., Schmidt et al., 1989). There appears to be a limit to the benefit of the size of summaries, however, with the optimal summary size dependent on the task demands (Schmidt et al., 1990; Guadagnoli et al., 1996). Yao et al. (1994) provided a convincing demonstration of the effect of both summary size and summary type; their results are illustrated in **Figure 8**. However, retention performance was facilitated by moderately sized (five-trial) summaries, compared to both the every-trial KR and larger (15-trial) summaries. This finding was present regardless of whether the summary information was presented as a graph of the individual trials or as a statistical average of the summarized trials.

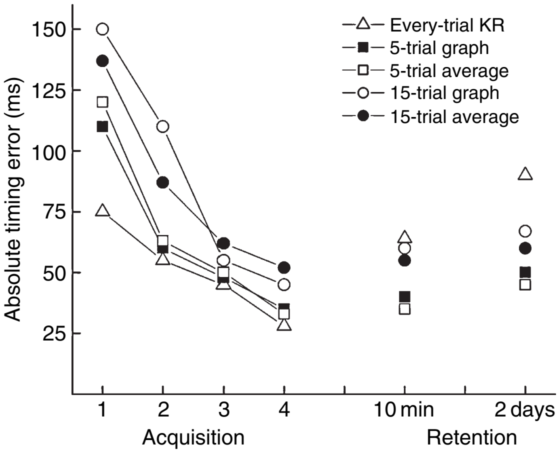


**Figure 8** Moderately-sized (5-trial) summaries facilitated timing error in retention, relative to every-trial KR and larger (15-trial) summary sizes. Data from Yao W, Fischman MG, and Wang YT (1994) Motor skill acquisition and retention as a function of average feedback, summary feedback, and performance variability. *J. Mot. Behav.* 26: 273–282.

The product of learning under these conditions of the temporal delivery of KR suggests that memory is affected in different ways. Conditions of practice during which KR is delivered such that it guides the learner toward producing the correct, or optimal, movement solution, are suboptimal to performance in retention. Providing KR concurrently or instantaneously upon movement completion are both conditions that fulfill the guiding role of KR. In contrast, delaying the delivery of KR is likely to lessen its immediate guidance function and, possibly, allow time for other learning factors to intervene. Such factors include a better understanding of one's movement-produced feedback, which is enhanced under conditions where the learner is encouraged to produce magnitude estimates of feedback during the delay period prior to KR delivery.

#### 2.34.6.2.3 The roles of knowledge results

Until the review of Salmoni et al. (1984), researchers had been content with the view that augmented information serves three roles in the acquisition of motor skills (Schmidt and Lee, 2005): (1) KR can be used as information by the learner to make permanent corrections in the actions being learned, (2) KR serves a motivating function that helps to maintain interest in the task and encourage continued practice, and (3) KR can provide a means to learn associations between motor commands and the sensory consequences of those commands. However, the finding that KR can serve a guidance role that has both positive effects (during practice) and negative learning consequences (i.e., in retention tests) suggested that the KR might be serving roles that had previously gone unnoticed.

Salmoni et al. (1984) and Schmidt (1991) speculated about two processes that might underlie these guidance effects. One idea is that successful motor learning involves the capability to understand and use the intrinsic feedback information that results from movement (such as proprioceptive and visual feedback). When KR is presented instantaneously and/or frequently, that information actively blocks or overshadows the processing of intrinsic feedback. Consequently, learning how to use intrinsic feedback when it is the only available source of information is degraded (e.g., when KR is removed in retention or otherwise is no longer available). An alternative view of these KR guidance effects suggests that the capability of a learner to correct errors is limited because of the natural, inherent variability of the motor system. However, often KR is provided without regard to what capabilities the learner possesses to use the information to make corrections to movement errors. In other words, the KR may encourage the learner to attempt to correct errors smaller than the learner's actual ability to control them; such attempts produce so-called maladaptive short-term corrections that may be beneficial for performance in practice, but are not beneficial for learning as measured on retention tests (Schmidt and Bjork, 1992).

In the previous section, we mentioned that one of the exciting, new directions in research concerns individual differences and the effects of self-determined schedules of practice. A similar line of investigation has also been undertaken with regard to the delivery of augmented feedback, and some intriguing findings are emerging. An early study (Janelle et al., 1997) revealed that retention was facilitated if learners were provided the control over the decision about whether or not to receive augmented feedback after a trial, relative to a yoked group (that controlled for the frequency, but not the decision to deliver feedback) and a group that received five-trial summaries. The benefit to learning for this self-determined group has been replicated in several experiments (e.g., Chiviacowsky and Wulf, 2002, 2005) and represents a curious effect. For example, in postexperiment interviews Chiviacowsky and Wulf (2002) found that individuals preferred to receive KR after trials on which they perceived that their performance had been relatively good. Additionally, Chiviacowsky and

Wulf (2005) found that the decision to receive feedback was more effective when made after the performance of a trial than when decided before a trial.

According to the guidance hypothesis, KR will have a detrimental effect on learning if it blocks or overshadows the learner's attempt to interpret his or her own movement-produced feedback relative to the information provided in the KR. The effects of self-determined KR are consistent with the guidance hypothesis to the extent that providing control of when KR is delivered gives the learner the opportunity to maximize the contrast between perceived KR and actual KR. However, these findings also contradict some basic theoretical arguments regarding how KR works. One consistent finding in the literature suggests that the usefulness of KR is optimized when it informs the learner about errors that had been made, not when it confirms to the learner that a trial had been performed well (Sherwood, 1988). Thus, similar to the research on practice schedules, individual differences in the learner's perception of ongoing performance, as well as their metacognitive strategies for how the delivery of KR is best suited to facilitate learning, are all likely to be important determiners of the effectiveness of augmented feedback.

## 2.34.7 Summary

Motor learning is the process by which the capability for skilled motor control becomes represented in memory. Motor memory is the product of learning. In this chapter, we have reviewed two theories regarding how memory for skill is developed. Both theories explain how the interaction of movement and feedback results in permanent representations that influence motor control. We suggest that future work needs to be done that further develops theories of motor learning that account for how and why cognitive factors influence the qualitative representations in memory.

## References


Adams JA (1971) A closed-loop theory of motor learning. *J. Mot. Behav.* 3: 111–150.

Adams JA (1987) Historical review and appraisal of research on the learning, retention, and transfer of human motor skills. *Psychol. Bull.* 101: 41–74.

Adams JA and Bray NW (1970) A closed-loop theory of paired-associate verbal learning. *Psychol. Rev.* 77: 385–405.

Agruss CD, Williams KR, and Fathallah FA (2004) The effect of feedback training on lumbosacral compression during simulated occupational lifting. *Ergonomics* 47: 1103–1115.

Albaret J-M and Thon B (1998) Differential effects of task complexity on contextual interference in a drawing task. *Acta Psychol.* 100: 9–24.

Anderson DI, Magill RA, and Sekiya H (2001) Motor learning as a function of KR schedule and characteristics of task-intrinsic feedback. *J. Mot. Behav.* 33: 59–66.

Anderson DI, Magill RA, Sekiya H, and Ryan G (2005) Support for an explanation for the guidance effect in motor skill learning. *J. Mot. Behav.* 37: 231–238.

Battig WF (1966) Facilitation and interference. In: Bilodeau EA (ed.) *Acquisition of Skill*, pp. 215–244. New York: Academic Press.

Battig WF (1979) The flexibility of human memory. In: Cermak LS and Craik FIM (eds.) *Levels of Processing in Human Memory*, pp. 23–44. Hillsdale, NJ: Erlbaum.

Battig WF and Shea JB (1980) Levels of processing of verbal materials: An overview. In: Klavora P and Flowers J (ed.) *Motor Learning and Biomechanical Factors in Sport*, pp. 24–33. Toronto: University of Toronto.

Bilodeau IM (1956) Accuracy of a simple positioning response with variation in the number of trials by which knowledge of results is delayed. *Am. J. Psychol.* 69: 434–437.

Book WF (1908/1925) *The Psychology of Skill*. Missoula: University of Montana. [Reprinted, New York: Gregg.]

Bourne LE Jr. and Archer EJ (1956) Time continuously on target as a function of distribution of practice. *J. Exp. Psychol.* 51: 25–33.

Boyd LA and Winstein CJ (2003) Impact of explicit information on implicit motor-sequence learning following middle cerebral artery stroke. *Phys. Ther.* 83: 976–989.

Bryan WL and Harter N (1897) Studies in the physiology and psychology of the telegraphic language. *Psychol. Rev.* 4: 27–53.

Bryan WL and Harter N (1899) Studies on the telegraphic language: The acquisition of a hierarchy of habits. *Psychol. Rev.* 6: 345–375.

Brydges R, Carnahan H, Backstein D, and Dubrowski A (2007) Application of motor learning principles to complex surgical tasks: Searching for the optimal practice schedule. *J. Mot. Behav.* 39: 40–48.

Chiviacowsky S and Wulf G (2002) Self-controlled feedback: Does it enhance learning because performers get feedback when they need it? *Res. Q. Exerc. Sport* 73: 408–415.

Chiviacowsky S and Wulf G (2005) Self-controlled feedback is effective if it is based on the learner's performance. *Res. Q. Exerc. Sport* 76: 42–48.

Cuddy LJ and Jacoby LL (1982) When forgetting helps memory. An analysis of repetition effects. *J. Verbal Learn. Verbal Behav.* 21: 451–467.

Dees V and Grindley GC (1951) The effect of knowledge of results on learning and performance: IV. The direction of the error in very simple skills. *Q. J. Exp. Psychol.* 3: 36–42.

Descarreaux M, Dugas C, Lalanne K, Vincelette M, and Normand MC (2006) Learning spinal manipulation: The importance of augmented feedback relating to various kinetic parameters. *Spine J.* 6: 138–145.

Dubrowski A, Backstein D, Abughaduma R, Leidl D, and Carnahan H (2005) The influence of practice schedules in the learning of a complex bone-plating surgical task. *Am. J. Surg.* 190: 359–363.

Elwell JL and Grindley GC (1938) The effect of knowledge of results on learning and performance. *Br. J. Psychol.* 29: 39–54.

Guadagnoli MA and Lee TD (2004) Challenge point: A framework for conceptualizing the effects of various practice conditions in motor learning. *J. Mot. Behav.* 36: 212–224.

Guadagnoli MA, Dornier LA, and Tandy RD (1996) Optimal length for summary knowledge of results: The influence of

task-related experience and complexity. *Res. Q. Exerc. Sport* 67: 239–248.
Hall KG and Magill RA (1995) Variability of practice and contextual interference in motor skill learning. *J. Mot. Behav.* 27: 299–309.
Hall KG, Domingues DA, and Cavazos R (1994) Contextual interference effects with skilled baseball players. *Percept. Mot. Skills* 78: 835–841.
Henry FM and Rogers DE (1960) Increased response latency for complicated movements and a ''memory drum'' theory of neuromotor reaction. *Res. Q.* 31: 448–458.
Hill LB (1934) A quarter century of delayed recall. *Pedag. Semin. J. Genet. Psychol.* 44: 231–238.
Hill LB (1957) A second quarter century of delayed recall or relearning at 80. *J. Educ. Psychol.* 48: 65–68.
Hill LB, Rejall AE, and Thorndike EL (1913) Practice in the case of typewriting. *Pedag. Semin.* 20: 516–529.
Hull CL (1943) *Principles of Behavior*. New York: Appleton-Century-Crofts.
Immink MA and Wright DL (1998) Contextual interference: A response planning account. *Q. J. Exp. Psychol.* 51A: 735–754.
Immink MA and Wright DL (2001) Motor programming during practice conditions high and low in contextual interference. *J. Exp. Psychol. Hum. Percept. Perform.* 27: 423–437.
Irion AL (1966) A brief history of research on the acquisition of skill. In: Bilodeau EA (ed.) *Acquisition of Skill*, pp. 1–46. New York: Academic Press.
Jacoby LL (1978) On interpreting the effects of repetition: Solving a problem versus remembering a solution. *J. Verbal Learn. Verbal Behav.* 17: 649–667.
Janelle CM, Barba DA, Frehlich SG, Tennant LK, and Cauraugh JH (1997) Maximizing performance feedback effectiveness through videotape replay and a self-controlled learning environment. *Res. Q. Exerc. Sport* 68: 269–279.
Keele SW (1968) Movement control in skilled motor performance. *Psychol. Bull.* 70: 387–403.
Keetch KM, Schmidt RA, Lee TD, and Young DE (2005) Especial skills: Their emergence with massive amounts of practice. *J. Exp. Psychol. Hum. Percept. Perform.* 31: 970–978.
Keetch KM and Lee TD (in press) The effect of self-regulated and experimenter-imposed practice schedules on motor learning for tasks of varying difficulty. *Res. Q. Exerc. Sport*.
Klapp ST (1996) Reaction time analysis of central motor control. In: Zelaznik HN (ed.) *Advances in Motor Learning and Control*, pp. 13–35. Champaign, IL: Human Kinetics.
Koerth W (1922) A pursuit apparatus: Eye-hand coordination. *Psychol. Monogr.* 31: 228–292.
Krakauer JW (2006) Motor learning: Its relevance to stroke recovery and neurorehabilitation. *Curr. Opin. Neurol.* 19: 84–90.
Lavery JJ (1962) Retention of simple motor skills as a function of type of knowledge of results. *Can. J. Psychol.* 16: 300–311.
Lee TD and Genovese ED (1988) Distribution of practice in motor skill acquisition: Learning and performance effects reconsidered. *Res. Q. Exerc. Sport* 59: 277–287.
Lee TD and Magill RA (1983) The locus of contextual interference in motor-skill acquisition. *J. Exp. Psychol. Learn. Mem. Cogn.* 9: 730–746.
Lee TD and Magill RA (1985) Can forgetting facilitate skill acquisition? In: Goodman D, Wilberg RB, and Franks IM (eds.) *Differing Perspectives in Motor Learning, Memory, and Control*, pp. 3–22. Amsterdam: Elsevier.
Lee TD, Magill RA, and Weeks DJ (1985) Influence of practice schedule on testing schema theory predictions in adults. *J. Mot. Behav.* 17: 283–299.
Lee TD, Wishart LR, Cunningham S, and Carnahan H (1997) Modeled timing information during random practice eliminates the contextual interference effect. *Res. Q. Exerc. Sport* 68: 100–105.
Lee TD, Wulf G, and Schmidt RA (1992) Contextual interference in motor learning: Dissociated effects due to the nature of task variations. *Q. J. Exp. Psychol.* 44A: 627–644.
Li Y and Wright DL (2000) An assessment of the attention demands during random- and blocked-practice schedules. *Q. J. Exp. Psychol.* 53A: 591–606.
MacPherson SJ, Dees V, and Grindley GC (1948) The effect of knowledge of results on learning and performance: II. Some characteristics of very simple skills. *Q. J. Exp. Psychol.* 1: 68–78.
MacPherson SJ, Dees V, and Grindley GC (1949) The effect of knowledge of results on learning and performance: III. The influence of time intervals between trials. *Q. J. Exp. Psychol.* 1: 167–174.
Magill RA and Hall KG (1990) A review of the contextual interference effect in motor skill acquisition. *Hum. Movement Sci.* 9: 241–289.
McCracken HD and Stelmach GE (1977) A test of the schema theory of discrete motor learning. *J. Mot. Behav.* 9: 193–201.
McGeoch JA (1927) The acquisition of skill. *Psychol. Bull.* 24: 437–466.
McGeoch JA (1929) The acquisition of skill. *Psychol. Bull.* 26: 457–498.
McGeoch JA (1931) The acquisition of skill. *Psychol. Bull.* 28: 413–466.
McGeoch JA and Irion AL (1952) *The Psychology of Human Learning*. New York: Longmans.
Rosenbaum DA (2005) The Cinderella of psychology: The neglect of motor control in the science of mental life and behavior. *Am. Psychol.* 60: 308–317.
Salmoni AW, Schmidt RA, and Walter CB (1984) Knowledge of results and motor learning: A review and critical reappraisal. *Psychol. Bull.* 95: 355–386.
Schmidt RA (1975) A schema theory of discrete motor skill learning. *Psychol. Rev.* 82: 225–260.
Schmidt RA (1985) The search for invariance in skilled movement behavior. *Res. Q. Exerc. Sport* 56: 188–200.
Schmidt RA (1991) Frequent augmented feedback can degrade learning: Evidence and interpretations. In: Requin J and Stelmach GE (eds.) *Tutorials in Motor Neuroscience*, pp. 59–75. Dordrecht: Kluwer.
Schmidt RA and Bjork RA (1992) New conceptualizations of practice: Common principles in three paradigms suggest new concepts for training. *Psychol. Sci.* 3: 207–217.
Schmidt RA and Lee TD (2005) *Motor Learning: A Behavioral Emphasis*, 4th edn. Champaign, IL: Human Kinetics.
Schmidt RA and White JL (1972) Evidence for an error detection mechanism in motor skills: A test of Adams' closed-loop theory. *J. Mot. Behav.* 4: 143–153.
Schmidt RA and Wulf G (1997) Continuous concurrent feedback degrades skill learning: Implications for training and simulation. *Hum. Factors* 39: 509–525.
Schmidt RA, Young DE, Swinnen S, and Shapiro DC (1989) Summary knowledge of results for skill acquisition: Support for the guidance hypothesis. *J. Exp. Psychol. Learn. Mem. Cogn.* 15: 352–359.
Schmidt RA, Lange C, and Young DE (1990) Optimizing summary knowledge of results for skill learning. *Hum. Movement Sci.* 9: 325–348.
Sekiya H, Magill RA, Sidaway B, and Anderson DI (1994) The contextual interference effect for skill variations from the same and different generalized motor programs. *Res. Q. Exerc. Sport* 65: 330–338.
Sekiya H, Magill RA, and Anderson DI (1996) The contextual interference effect in parameter modifications of the same generalized motor program. *Res. Q. Exerc. Sport* 67: 59–68.

Shapiro DC and Schmidt RA (1982) The schema theory: Recent evidence and developmental implications. In: Kelso JAS and Clark JE (eds.) *The Development of Movement Control and Co-ordination*, pp. 113–150. New York: Wiley.

Shea CH and Kohl RM (1991) Composition of practice: Influence on the retention of motor skills. *Res. Q. Exerc. Sport* 62: 187–195.

Shea JB and Morgan RL (1979) Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *J. Exp. Psychol. Hum. Learn. Mem.* 5: 179–187.

Shea CH and Wulf G (2005) Schema theory: A critical appraisal and reevaluation. *J. Mot. Behav.* 37: 85–101.

Shea JB and Zimny ST (1988) Knowledge incorporation in motor representation. In: Meijer OG and Roth K (eds.) *Complex Movement Behaviour: 'The' Motor-Action Controversy*, pp. 289–314. Amsterdam: Elsevier.

Sherwood DE (1988) Effect of bandwidth knowledge of results on movement consistency. *Percept. Motor Skills* 66: 535–542.

Simon DA and Bjork RA (2001) Metacognition in motor learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 907–912.

Simon DA and Bjork RA (2002) Models of performance in learning multisegment movement tasks: Consequences for acquisition, retention, and judgments of learning. *J. Exp. Psychol. Appl.* 8: 222–232.

Snoddy GS (1926) Learning and stability: A psychophysical analysis of a case of motor learning with clinical applications. *J. Appl. Psychol.* 10: 1–36.

Ste-Marie DM, Clark SE, Findlay LC, and Latimer AE (2004) High levels of contextual interference enhance handwriting skill acquisition. *J. Mot. Behav.* 36: 115–126.

Swinnen SP, Schmidt RA, Nicholson DE, and Shapiro DC (1990) Information feedback for skill acquisition: Instantaneous knowledge of results degrades learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 706–716.

Thorndike EL (1927) The law of effect. *Am. J. Psychol.* 39: 212–222.

Van Rossum JHA (1990) Schmidt's schema theory: The empirical base of the variability of practice hypothesis. A critical analysis. *Hum. Movement Sci.* 9: 387–435.

Verdolini K and Lee TD (2004) Motor learning principles of intervention. In: Sapienza C and Casper J (eds.) *For Clinicians by Clinicians: Vocal Rehabilitation in Medical Speech-Language Pathology*, pp. 403–446. Austin, TX: Pro-Ed.

Wierinck E, Puttemans V, and van Steenberghe D (2006) Effect of reducing frequency of augmented feedback on manual dexterity training and its retention. *J. Dent.* 34: 641–647.

Williams AM and Hodges NJ (eds.) (2004) *Skill Acquisition in Sport: Research, Theory and Practice*. London: Routledge.

Winstein CJ and Schmidt RA (1990) Reduced frequency of knowledge of results enhances motor skill learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 677–691.

Wright DL (1991) The role of intertask and intratask processing in acquisition and retention of motor skills. *J. Mot. Behav.* 23: 139–145.

Wulf G and Schmidt RA (1996) Average KR degrades parameter learning. *J. Mot. Behav.* 28: 371–381.

Wulf G and Shea CH (2002) Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychon. Bull. Rev.* 9: 185–211.

Wulf G, Schmidt RA, and Deubel H (1993) Reduced feedback frequency enhances generalized motor program learning but not parameterization learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 19: 1134–1150.

Yao W, Fischman MG, and Wang YT (1994) Motor skill acquisition and retention as a function of average feedback, summary feedback, and performance variability. *J. Mot. Behav.* 26: 273–282.

Yiu EM, Verdolini K, and Chow LP (2005) Electromyographic study of motor learning for a voice production task. *J. Speech Lang. Hear. Res.* 48: 1254–1268.

# 2.35 The Role of Sleep in Memory Consolidation

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## 2.35.1 The Role of Sleep in Memory Consolidation

We spend about a third of our lives sleeping, yet in spite of decades of scientific inquiry, the function of sleep remains an enigma. This is not to say that progress has not been made. From antiquity until the 1950s, sleep was generally believed to be a state of inactivity where the brain was turned off and the body rested, but we now know that the sleeping brain can be equally, and sometimes more, active than the brain in its awake state. Even during deep or slow wave sleep, when the brain is relatively quiescent compared to rapid eye movement sleep or wakefulness, it is still roughly 80% activated and thus capable of elaborate information processing (Steriade, 1999; Hobson, 2005).

Numerous hypotheses have been put forward to explain the functions of sleep, including energy conservation, brain detoxification, immune regulation, tissue restoration, and predator avoidance. More recently, the hypothesis that sleep plays a key role in the consolidation of memories has gained considerable attention (Smith, 1985; Maquet, 2001; Smith, 2001; Stickgold et al., 2001). Following two seminal papers in 1994 (Karni et al., 1994; Wilson and McNaughton, 1994), the publication rate on this topic increased fivefold over the next 10 years (Stickgold and Walker, 2005).

Despite this resurgence of attention, the question of how sleep contributes to memory consolidation is actually quite old. In the first century AD, the Roman rhetorician Quintilian, commenting on the benefits of sleep, noted that "what could not be repeated at first is readily put together on the following day; and the very time which is generally thought to cause forgetfulness is found to strengthen the memory."

In this chapter, we review the accumulating evidence supporting a sleep–memory connection, which converges from studies at the molecular, cellular, physiological, and behavioral levels of analysis (Maquet, 2001; Smith, 2001; McNaughton et al., 2003; see also Gais and Born, 2004a; Stickgold, 2005; but see Vertes and Siegel, 2005). We begin with a précis of the field's history before turning to a review of its present status. We attempt to operationally define the terms sleep and memory, and offer our opinions on the field's strengths and shortcomings. In the first half of this chapter, we examine sleep's role in the strengthening of perceptual and procedural skills, and in the second half, we devote our attention to sleep's role in the consolidation of episodic memories. Our primary intention is to alert memory researchers to the growing field of sleep and memory, as well as to spark enthusiasm for a new way of researching memory systems that holds much promise for understanding both sleep and memory.

Although our review covers mainly behavioral and physiological evidence in humans, we point the interested reader to a growing animal literature on this topic. Numerous studies have examined the reactivation of neuronal patterns during post-training sleep, which show that neuronal activation sequences associated with various memory tasks are replayed during subsequent sleep. We touch briefly upon these studies toward the end of the chapter, but we refer the reader to the following articles for a deeper understanding of this fascinating topic (Wilson and McNaughton, 1994; Qin et al., 1997; McNaughton et al., 2003; Sirota et al., 2003; Ribeiro and Nicolelis, 2004). Other studies have begun to illuminate the molecular aspects of sleep-dependent memory consolidation, which we will not discuss here, but which certainly deserve attention as well (Smith et al., 1991; Nakanishi et al., 1997; Ribeiro et al., 1999; Graves et al., 2001; Benington and Frank, 2003).

## 2.35.2 Definitions of Sleep and Memory

Before turning to a discussion of the relationship between sleep and memory, we will first attempt to define both terms, as confusion has often arisen due to oversimplifications of one or both. We thus begin the chapter with a brief overview of the neurobiological characteristics associated with the various stages of sleep, and the different types of memory.

## 2.35.3 Stages of Sleep

Sleep progresses through a series of stages, which can be divided broadly into rapid eye movement or REM sleep (also called paradoxical sleep, due to the many wake-like features seen in this sleep stage), and non-rapid eye movement or NREM sleep. NREM sleep can be further subdivided into four NREM stages (1–4) corresponding, in that order, to increasing depth of sleep (Rechtschaffen and Kales, 1968). Slow wave sleep (stages 3 and 4) is the deepest of the NREM phases, and is the phase from which people have the most difficulty awakening.

In healthy adults, NREM and REM sleep alternate in approximately 90-min cycles throughout the night (so-called ultradian cycles). However, the relative contributions of NREM and REM sleep to these cycles varies across the night, with more of NREM stages 3 and 4 (slow wave sleep, SWS) early in the night, and more REM sleep late in the night. Thus, more than 80% of a night's SWS is concentrated in the first half of the night, while the second half of the night contains roughly twice as much REM sleep as the first half. This distribution of sleep stages has implications for some of the research paradigms described later in this chapter.

As NREM sleep progresses from stage 1 through stages 3 and 4 (SWS), electroencephalographic (EEG) activity steadily slows. In stage 1 sleep (drowsiness) there is an attenuation of the normally occurring alpha rhythm (8–13 Hz). In its place, a mixture of frequencies with a slower theta frequency (4–7 Hz) begin to emerge. Stage 2 NREM sleep is characterized by a continued reduction in EEG frequencies combined with two signature waveforms: large electrical sharp waves called K complexes and short synchronized bursts of 11- to 16-Hz oscillations called sleep spindles. Slow wave sleep is characterized by high-voltage, low-frequency (<4 Hz) EEG oscillations, which are an expression of underlying synchrony between the thalamus and cerebral cortex (Amzica and Steriade, 1995).

REM sleep, on the other hand, is characterized by low-amplitude, mixed-frequency EEG oscillations that are similar to the EEG patterns seen in wake. Periodic bursts of rapid eye movement also occur, along with a nearly complete loss of muscle tone.

As the brain passes through these sleep stages, it undergoes marked neurochemical alterations. In NREM sleep, acetylcholine neurons in the brainstem and forebrain become strikingly less active (Hobson et al., 1975) and serotonergic and noradrenergic neurons also reduce their firing rates relative to waking levels. In REM sleep, both of these aminergic systems are strongly inhibited, while acetylcholine neurons become intensely active, in some cases more active than in wake (Marrosu et al., 1995). The brain in REM sleep is thus largely devoid of aminergic modulation and dominated by acetylcholine. Thus, sleep consists of myriad physiological states and many neurochemical and neurohormonal mechanisms. When considering the role of sleep in memory consolidation, one must take this dynamic model of sleep into account (Payne and Nadel, 2004; Walker and Stickgold, 2004).

## 2.35.4 Types of Memory

Like sleep, memory can be subdivided into different types. In contrast to earlier perspectives, in which memory was viewed as a single system subserved by a restricted part of the brain, most modern views posit several types of memory, each obeying different rules of operation, and each drawing on distinct neural systems that interact to produce the subjective sense of remembering. This insight is critical if we are to understand the role of sleep in human memory consolidation because it raises the possibility of many complex interactions among the dynamic processes of sleep and memory, where the neurochemistry associated with distinct sleep/brain states differentially influences the various types of memory.

Various taxonomies are used to classify the different memory systems (Schacter and Tulving, 1994), most of which agree on a distinction between two broad classes of memory. First, there are memories of the events in our lives and the knowledge of the world that we obtain from these events. Typically, this class of memories can be explicitly retrieved, and for this reason it is often referred to as explicit or declarative (i.e., that which can be declared). Second, there are memories for the various skills, procedures, and habits we acquire through experience – so-called 'how-to' memories. These memories are not so easily made explicit and are usually only evident through performance improvements in various behaviors. Thus, this class of memories is referred to as procedural or implicit. The neural mechanisms that support these memory systems appear to be partially dissociable; however, it is important to remember that they interact as well.

Explicit memory can be further subdivided into episodic and semantic memories (Tulving, 1972). Episodic memory concerns those aspects of explicit remembering that incorporate the specific context of an experienced event, including the time and place of its occurrence. Semantic memory, on the other hand, is concerned with the knowledge one acquires during events, but is itself separated from the specific event in question. Thus, our knowledge about the meaning of words and facts about the world, though acquired in the context of some specific experience, appears to be stored in a form that is context-independent (e.g., not bound to the originating context).

Beyond these, there is also evidence for an emotional memory system that mediates the encoding and consolidation of emotionally charged events (McGaugh et al., 1993; Cahill and McGaugh, 1996; McGaugh et al., 1996; Cahill, 2000; Packard and Cahill, 2001). This system is particularly concerned with learning about fearful and unpleasant stimuli, although growing evidence suggests it plays a role in memory for pleasant information as well (Hamann et al., 1999; Hamann et al., 2002; Hamann, 2003; Kensinger, 2004).

The explicit memory system is governed by the hippocampus and surrounding medial temporal areas, while procedural and implicit memory are thought to be independent of the hippocampal complex, relying instead on various subcortical and neocortical structures (Squire, 1992; Schacter and Tulving, 1994). The emotional memory system is critically modulated by the amygdala, a limbic structure located deep in the subcortical brain and richly connected to the hippocampus. It is important to note that because each of these memory systems is subserved by different brain areas, information dependent on each is open to differential processing during sleep. Thus, when attempting to answer the seemingly straightforward question – how does sleep influence memory? – we find that it quickly branches into numerous questions, depending on what kind of sleep and what kind of memory we are talking about.

Although memory consolidation is a complex, multistep process, we define it here as a slow process that converts a still-labile memory trace into a more stable or enhanced form (e.g., Dudai, 2004). As such, the benefits of sleep are sometimes seen as a reduction in the normal decay of a memory (assessed via performance on a memory task), while other times they are seen as actual enhancements in performance.

## 2.35.5 Procedural and Implicit Memory

Sleep appears to benefit both procedural/implicit and explicit memory. Since most of the recent work has focused on sleep and procedural memory, we begin our review here. A wide range of perceptual, motor, and cognitive abilities are gradually acquired through continuous interactions with the environment, and in many cases this occurs in the absence of conscious awareness. Converging data suggest that these abilities are acquired slowly and are not attained solely during the learning episode. While some learning certainly develops quickly, performance on various tasks improves further, and without additional practice, simply through the passage of time (so-called off-line improvement), suggesting that memory traces continue to be processed over long periods of time. Importantly for our purposes, these longer periods often contain sleep, and the consolidation occurring during them may be dependent on this sleep.

### 2.35.5.1 Visual Discrimination Learning

Early work investigating the effect of sleep on implicit learning used a visual texture discrimination task (VDT) that was originally developed by Karni and Sagi (1991). The task requires participants to determine the orientation (vertical or horizontal) of an array of diagonal bars that is embedded in one visual quadrant against a background of exclusively horizontal bars (**Figure 1**). At the center of the screen is the fixation target, which is either the letter T or L. This target screen is succeeded first by a blank screen for a variable interstimulus interval (ISI), and then by a mask (a screen covered with randomly oriented V letters, with a superimposed V and L in the center). Subjects must determine the orientation of the array, and the performance is estimated by the ISI corresponding to 80% correct responses (Karni and Sagi, 1993; Karni et al., 1994).

Amnesic patients with damage to the hippocampal complex, who cannot acquire knowledge explicitly, show normal performance improvements on the VDT. This was shown using a group of five densely amnesic patients. All five had extensive medial temporal lobe damage, including damage to the hippocampal formation. These patients were trained on the task on day 1 and retested on days 2 and 5. In spite of having no conscious recollection of having taken the test before, they showed substantially improved performance (Stickgold, 2003).

In neurologically normal subjects, improvement on the VDT develops slowly after training (Karni and Sagi, 1993; Stickgold et al., 2000a), with no improvement when retesting occurs on the same day as training (**Figure 2(a)**, open circles). Instead, improvement is only observed after a night of sleep (**Figure 2(a)**, filled circles).

This was true even for a group of subjects that were retested only 9 h after training. Importantly, there was not even a trend to greater improvement when the training–retest interval was increased from 9 to 22.5 h, suggesting that additional wake time after the night of sleep provided no additional benefit. While further wake time provided no benefit, additional nights of sleep did produce incremental improvement. When subjects were retested 2–7 days after training, 50% greater improvement was observed than after a single night of sleep (**Figure 2(b)**, green bars). Critically, another group of subjects was sleep-deprived on the first night after training. These subjects were allowed two full nights of recovery sleep before being retested 3 days later. They failed to show any residual learning, suggesting that performance enhancements are dependent on a normal first night of sleep (**Figure 2(b)**, red bar). Time alone is clearly not enough to produce

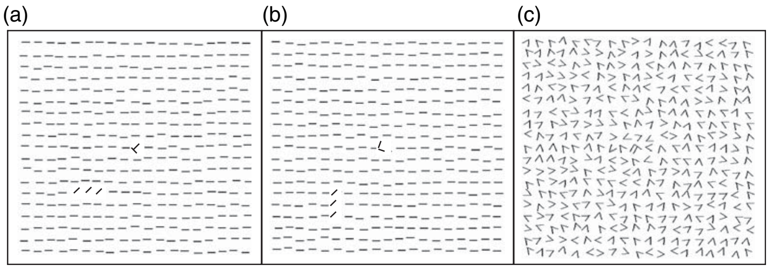


**Figure 1** Sample screens from the visual texture discrimination task (VDT). See text for explanation.

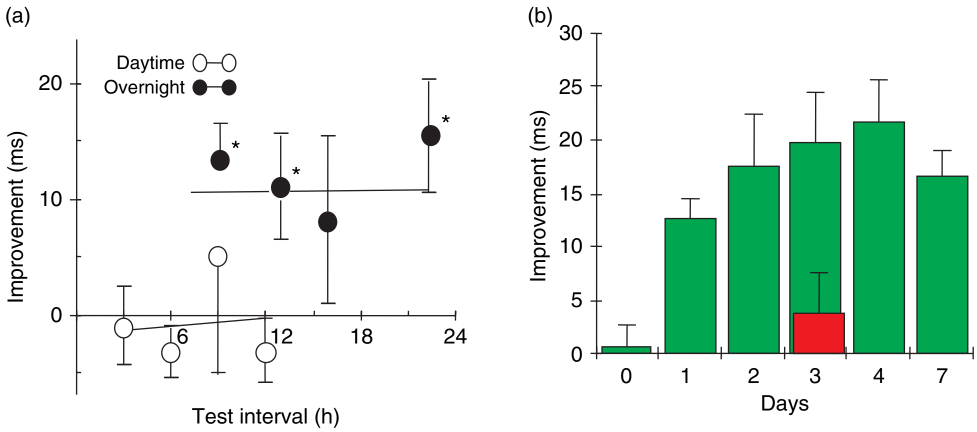


**Figure 2** Sleep-dependent improvement on the VDT. All subjects were trained and then retested only a single time. Each point in (a) and each bar in (b) represents a separate group of subjects. Error bars in (a) and (b) are S.E.M.s. From Stickgold R, James L, and Hobson A (2000a) Visual discrimination learning requires post-training sleep. *Nat. Neurosci.* 2(12): 1237–1238; Stickgold R, Whidbee D, et al. (2000b) Visual discrimination task improvement: A multi-step process occurring during sleep. *J. Cogn. Neurosci.* 12: 246–254.

long-term benefits from VDT training. It appears that sleep is also required (Stickgold et al., 2000a).

Initially, improvement on this task appeared to depend solely on REM sleep, because subjects who underwent selective deprivation of REM sleep showed no improvement on the task (Karni et al., 1994). Later studies, however, showed that optimal performance on this task requires both SWS and REM sleep (Stickgold et al., 2000b).

When subjects were trained and their subsequent sleep monitored in the sleep laboratory, the amount of improvement was proportional to the amount of SWS during the first quarter of the night (**Figure 3(a)**), as well as to the amount of REM sleep in the last quarter (**Figure 3(b)**). Indeed, the product of these two sleep parameters explained more than 80% of the intersubject variance (**Figure 3(d)**). No significant correlations were found for sleep stages during other parts of the night (**Figure 3(c)**) or for the amount of Stage 2 sleep at any time during the night.

Gais et al. (2000) came to a similar conclusion by examining improvement after 3 h of sleep either early or late in the night. They found that 3 h of early night sleep, which was rich in SWS, produced an 8-ms improvement; but after a full night of sleep, which added REM-rich sleep late in the night, a 26-ms improvement was observed, three times that seen with early sleep alone. Interestingly, however, 3 h of REM-rich, late-night sleep actually produced deterioration in performance (Gais et al., 2000).

Daytime naps also lead to performance benefits on the VDT. To lay the groundwork for the nap studies, Mednick et al. (2002) showed that VDT performance suffers from repeated, same-day testing. When subjects were trained on the task and then tested at numerous time points throughout the day, their performance deteriorated (i.e., their ISI threshold was higher). **Figure 4** depicts tests given at 9.00 a.m., 12.00 p.m., 4.00 p.m., and 7.00 p.m., with performance worsening significantly on each successive test. However, if subjects are allowed to take an afternoon nap after the second test, their performance improves. Interestingly, 30-min naps prevented the normal deterioration seen during sessions 3 and 4 (Mednick et al., 2002), and longer naps ranging from 60 to 90 min, and containing both SWS and REM sleep, actually enhance performance (Mednick et al., 2003). Taken together, these studies suggest that both SWS and REM sleep play roles in the sleep-dependent memory consolidation of this task.

At this point, sleep's role in visual discrimination learning (as measured by VDT performance) is clear. But the VDT represents a very specific type of sensory memory that may or may not share its sleep dependency with other procedural tasks. This raises the question of whether the sleep effects observed with the VDT generalize to other forms of procedural memory. Studies of sleep-dependent auditory and motor skill learning strongly suggest that they do.

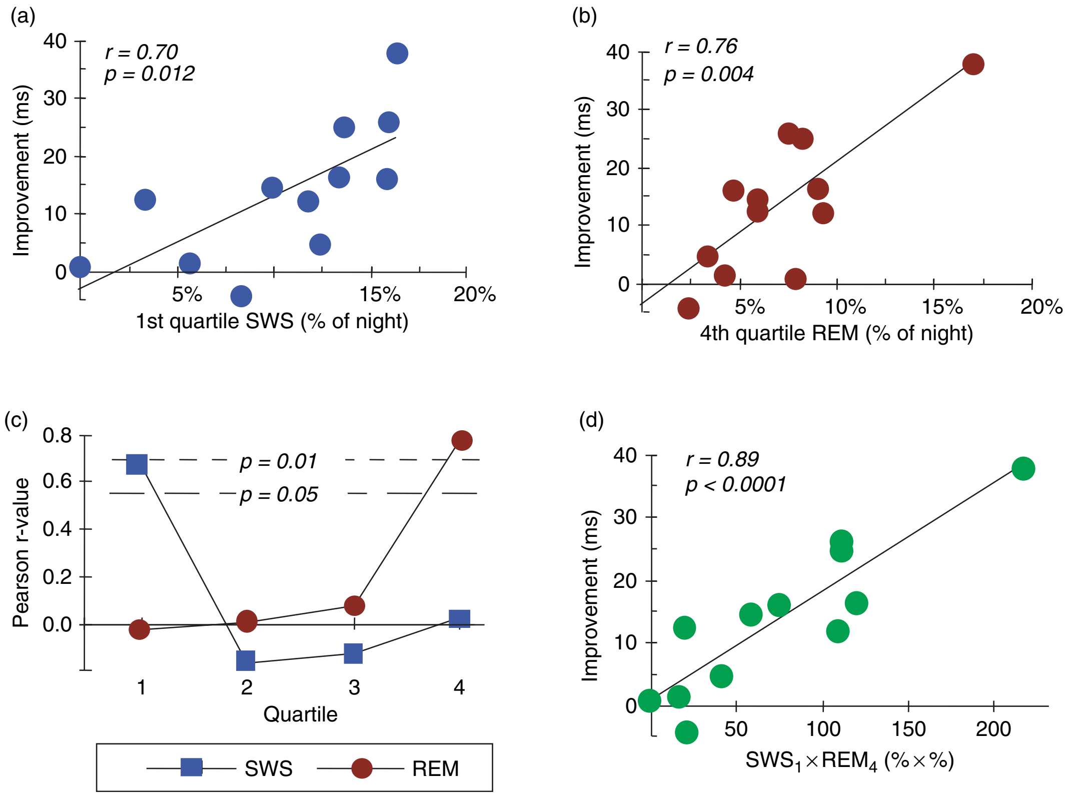


**Figure 3** REM and SWS dependence of VDT learning. From Stickgold R, Whidbee D, Schirmer B, et al. (2000b) Visual discrimination task improvement: A multi-step process occurring during sleep. *J. Cogn. Neurosci.* 12: 246–254.

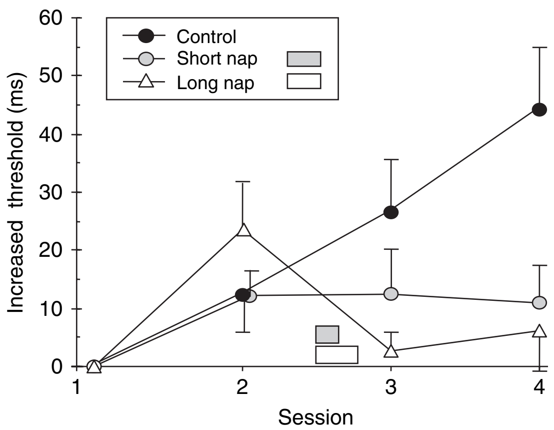


**Figure 4** Deterioration in VDT performance with repeated same-day testing and recovery following napping. Note that the ordinate reflects changes in ISI threshold and, as such, higher values indicate worse performance. From Mednick SC, Nakayama K, Cantero JL, et al. (2002) The restorative effect of naps on perceptual deterioration. *Nat. Neurosci.* 5: 677–681.

### 2.35.5.2 Auditory Learning

Gaab et al. (2004) have shown that delayed performance improvements in memory for pitch develop only across periods of sleep and not across similar periods spent awake. Atienza and colleagues (Atienza et al., 2002, 2004) have also presented evidence of both time- and sleep-dependent auditory memory consolidation, including sleep-dependent changes in brain-evoked response potentials (ERPs). Although post-training sleep deprivation did not prevent continued behavioral improvements, ERP changes associated with the automatic shift of attention to relevant stimuli, which normally develop in the 24–72 h after training, failed to develop following a posttraining night of sleep deprivation. These findings highlight the danger of presuming that a lack of behavioral improvement is equivalent to an absence of beneficial plastic changes in the brain, and they demonstrate the importance of using combined behavioral and physiological analyses (Gaab et al., 2004; Walker and Stickgold, 2006).

Finally, Fenn et al. (2003) have demonstrated that sleep benefits learning on a synthetic speech-recognition task. Training on a small set of words improved performance on novel words that used the same phoneme but a different acoustic pattern.

Importantly, sleep benefited this ability to generalize phonological categories across different acoustic patterns. Time spent awake after initial training resulted in a degradation of performance on this task, but a subsequent night of sleep restored it. This suggests a process of sleep-dependent consolidation capable of reestablishing previously learned complex auditory skill memory, as well as a form of sleep-dependent generalization of learning, which is a hallmark of flexible learning in humans (Fenn et al., 2003). These studies suggest that, as with visual discrimination learning, sleep provides an important benefit to auditory skill learning. In the next section, we show that motor memory benefits from sleep as well.

### 2.35.5.3 Motor Memory

Numerous studies have demonstrated a relationship between sleep and various types of motor memory (Smith and MacNeill, 1994; Fischer et al., 2002; Walker et al., 2002; Maquet et al., 2003). As an example, Walker et al. (2002) have demonstrated sleep-dependent improvements on a finger-tapping task. The task requires subjects to type the numeric sequence 4-1-3-2-4 as quickly and accurately as possible. Training consisted of twelve 30-s trials, separated by 30-s rest periods. All subjects show considerable improvement during the 12 trials of the training session (a fast learning component), but 12 h later, subjects performed very differently depending on whether the 12-h interval was filled with time spent sleeping or time spent awake. When trained in the morning and retested 12 h later, only an additional nonsignificant 4% improvement was seen in performance, but when tested again the next morning, a large and robust (14%) improvement was seen (**Figure 5(a)**). The failure to improve during the daytime could not be due to interference from related motor activity because subjects who were required to wear mittens and refrain from fine motor activities during this time showed a similar pattern of wake/sleep improvement (**Figure 5(b)**).

In contrast, when subjects were trained in the evening, improvement was observed the following morning (after sleep), but not across an additional 12 h of wake (**Figure 5(c)**). Thus, improved performance resulted specifically from a night of sleep, as opposed to the simple passage of time. Curiously, unlike the findings for the VDT, overnight improvement on this task correlated with the amount of stage 2 NREM during the night, especially during the last quarter of the night. These findings are in agreement with those of Smith and colleagues (Smith and MacNeill, 1994; Tweed et al., 1999; Fogel et al., 2001), who have also shown that stage 2 sleep, and possibly the sleep spindles which reach peak density

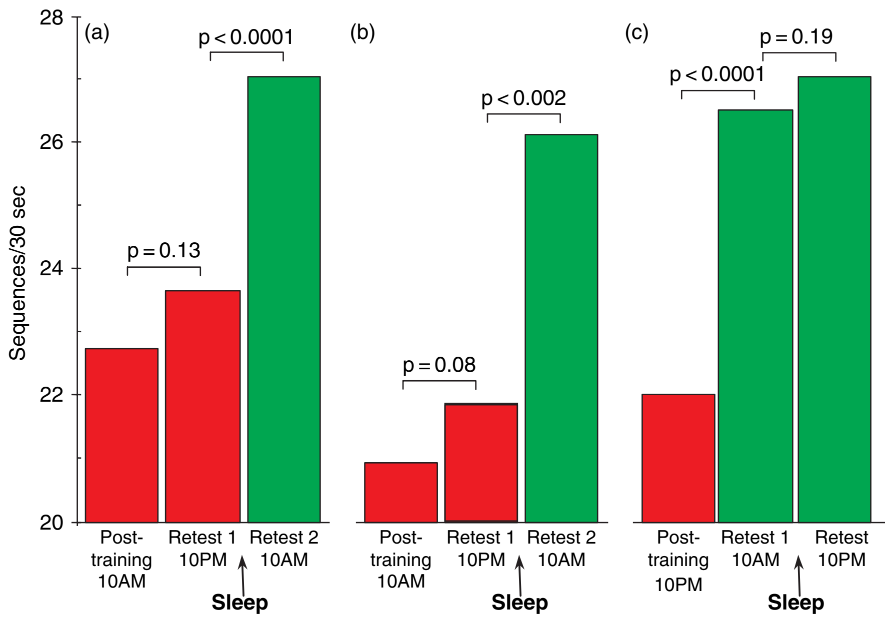


**Figure 5** Sleep-dependent motor learning. Improvement in speed was seen in all three groups over a night of sleep, but not over 12 h of daytime wake. From Walker MP, Brakefield T, Hobson JA, and Stickgold R (2002) Practice with sleep makes perfect: Sleep dependent motor skill learning. *Neuron* 35(1): 205–211.

during late night stage 2 sleep, are critical for simple motor memory consolidation. This seems plausible, as sleep spindles have been proposed to trigger intracellular mechanisms that are required for synaptic plasticity (Sejnowski and Destexhe, 2000).

It is important to note that this sleep-based improvement was not due to a speed/accuracy trade-off. When the number of errors per 30-s trial was compared between evening and morning, the number of errors actually decreased, although not significantly (Walker et al., 2002). However, when error rates (i.e., errors per sequence) were calculated, a highly significant 43% decrease inthe error rate was seen overnight (**Figure 6**), while a 20% increase in the error rate was found across 12 h spent awake (Walker et al. 2003).

At least for a simple motor task then, sleep appears to benefit both speed and accuracy. More recent studies have shown that these sleep-dependent benefits appear to be specific to both the motor sequence learned and the hand used to perform the task (Fischer et al., 2002; Korman et al., 2003).

This motor sequence task has been examined to determine where precisely in the motor program the sleep-dependent improvement occurs (Kuriyama et al., 2004). In the sequence mentioned above (4-1-3-2-4), there are four unique key-press transitions; 4 to 1, 1 to 3, 3 to 2, and 2 to 4. When the speed between transitions was analyzed for individual subjects prior to sleep, sticking points emerged. While some transitions were easy (i.e., fast), others were problematic (i.e., slow), as if the sequence was being parsed or chunked into smaller bits during presleep learning (Walker and Stickgold, 2006). After a night of sleep, these problematic points were preferentially improved, whereas transitions that had already been mastered prior to sleep did not change. Subjects who were trained and retested after a daytime wake interval showed no such improvements.

These findings suggest that the sleep-dependent consolidation process involves the unification of smaller motor memory units into a single motor memory representation, thereby improving problem points in the sequence. This overnight process would therefore offer a greater degree of performance automation, effectively optimizing speed across the motor program, and would explain the sleep-dependent improvements in speed and accuracy previously reported (Walker and Stickgold, 2006). But importantly, it suggests that the role of sleep is subtle and complex and does more than simply strengthen memories; sleep may encourage the restructuring and reorganization of memories – an important and often overlooked aspect of memory consolidation. We will return to this idea later in the chapter.

Fisher et al. (2002), using a different sequential finger-tapping task, which involves finger-to-thumb movements instead of keyboard typing, have shown

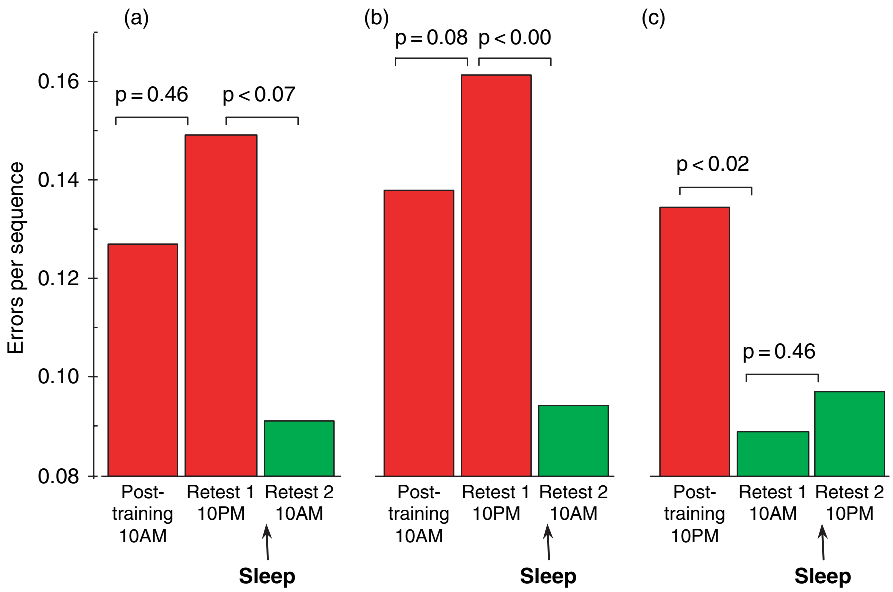


**Figure 6** Sleep-dependent motor learning. Improvement in accuracy was seen in all three groups over a night of sleep, but not over 12 h of daytime wake. From Walker MP, Brakefield T, Hobson JA, and Stickgold R (2002) Practice with sleep makes perfect: Sleep dependent motor skill learning. *Neuron* 35(1): 205–211.

that sleep following training is critical for delayed performance improvements. However, they found this improvement to be most strongly correlated with REM sleep rather than stage 2 NREM sleep (see 'Stages of sleep' above).

This discrepancy in sleep stage correlations mirrors similar discrepancies in the declarative memory section below, and remains to be resolved. Nonetheless, it is possible that the more novel finger-to-thumb task requires REM sleep, whereas the keyboard typing task, so similar to the well-learned typing most of us do regularly, is consolidated during stage 2 NREM sleep. A similarly subtle distinction has been reported by Robertson et al. (2004), who found that sleep-dependent enhancement of performance on a perceptual-motor sequence task again correlated with NREM, but only when subjects were explicitly aware of the presence of a repeating sequence, and not when knowledge of the sequence was gained only implicitly (Robertson et al., 2004).

Moving to another type of motor memory – motor adaptation – Maquet et al. (2003) showed that sleep benefits performance on a pursuit task. Participants were trained on a task in which the target trajectory was only predictable on the horizontal axis. This meant that optimal performance could only be achieved by developing an implicit model of the motion characteristics of the learned trajectory. Half of the subjects were sleep deprived on the first post-training night, while the other half were allowed to sleep normally. Three days later, after 2 full days of recovery sleep, performance was superior in the sleep group compared to the sleep-deprived group, and fMRI revealed that the superior temporal sulcus (STS) was differentially more active for the learned trajectory in subjects who slept than in sleep-deprived subjects. Moreover, increased functional connectivity was observed between the STS and the cerebellum, and between the supplementary eye field and the frontal eye field, suggestive of sleep-related plastic changes during motor skill learning in areas involved in smooth pursuit and eye movements.

Similarly, Smith and MacNeill (1994) demonstrated that selective stage 2 NREM sleep deprivation impairs memory for a pursuit rotor task and Huber et al. (2004) demonstrated improved performance on a motor reaching-adaptation task across a night of sleep, but not across an equivalent period of time spent awake. Here, daytime motor skill practice was accompanied by a subsequent increase in NREM slow-wave EEG activity over parietal cortex. This increase was proportional to the amount of delayed learning that developed overnight. Subjects who showed the greatest increase in slow-wave activity in the parietal cortex during NREM sleep showed the largest benefit in motor skill performance the following day (Huber et al., 2004).

Taken together, these findings strongly suggest that sleep is fundamentally important for the development of motor skill memory. Initial daytime learning benefits are supplemented by a night of sleep, which triggers additional learning without the need for further training. Although the role of the various sleep stages in skill memory remains unclear, overnight memory improvements tend to exhibit a strong relationship to NREM sleep, and, in some cases, to specific NREM sleep stages at specific times of the night (Walker and Stickgold, 2006).

Admittedly, visual discrimination, finger tapping, and motor adaptation are all relatively basic, low-level procedural tasks that may become automated fairly quickly. What about more complex implicit and procedural tasks? Animal work clearly demonstrates that complex tasks (e.g., instrumental conditioning, avoidance or maze learning) benefit from sleep, with rats showing increases in REM sleep that continue until the tasks are mastered (Smith et al., 1980; Smith and Wong, 1991; Hennevin et al., 1995). For instance, Smith and Wong (1991) trained rats on a complex operant bar press task, on which only some rats demonstrated increases in REM sleep after training. This split successfully predicted which rats would improve on the task and which rats would fail. Furthermore, after training rats on an avoidance task, Datta (2000) observed an increase in PGO waves (waves of neural activity that are generated in the pons and activate the forebrain during REM sleep) during the first four post-training REM sleep episodes. Changes in REM density observed during the first three of these episodes were proportional to improvement in task performance. These data suggest that the activation of pontine cells that generate PGO waves during REM sleep lead in turn to the activation of forebrain and cortical structures involved in memory consolidation and perhaps to the initiation of these consolidation processes (Datta, 2000).

Recently, Datta and colleagues examined whether the activation of PGO waves could reverse the learning impairment seen after REM sleep deprivation. Rats were trained on a two-way avoidance-learning task and either slept normally or underwent REM sleep deprivation. In addition, they either received a saline injection (placebo) or a carbachol injection in the P-wave generator. The rats that received both saline and REM sleep deprivation showed learning deficits when compared with the saline-injected rats that slept. But a carbachol-induced activation of PGO waves prevented this learning impairment in the sleep-deprived rats, suggesting that the PGO waves mediated the normal sleep-based memory consolidation (Datta et al., 2004).

Depriving rats of REM sleep after training also leads to performance deficits in complex skills, particularly if the deprivation occurs during so-called critical periods or paradoxical sleep windows (Smith et al., 1995; Smith and Rose, 1996). Two such critical periods emerged in rats attempting to learn a shuttle avoidance task when 20 trials per day were given over a 5-day period. The first occurred 9–12 h after training and the second occurred 17–20 h after training. If the rats were deprived of REM sleep during these windows, their memory for the task was significantly impaired. However, with more intensive training, the window appears earlier. When rats were given 100 training trials in a single session, the critical period appeared at 1–4 h after the end of the shuttle avoidance training (Smith and Butler, 1982).

Critical periods thus appear to vary depending on the task and the intensity of training, and hint at the complexity of sleep–memory relationships that we discuss later. Nonetheless, critical periods are thought to mirror the time after acquisition when REM sleep would typically increase over normal levels. These REM windows may not be prevalent in humans, however, who appear to be sensitive to deprivation during any REM period when trying to learn new complex skills (Smith, 1995).

REM sleep has been implicated in complex procedural learning in humans as well. In a PET (positron emission tomography) study of visuomotor skill memory using the serial reaction time task (SRTT) (Maquet et al., 2000), six spatially permanent position markers were shown on a computer screen and subjects watched for stimuli to appear below these markers. When a stimulus appeared in a particular position, subjects reacted as quickly as possible by pressing a corresponding key on the keyboard. Because the stimuli were generated in an order defined by a probabilistic finite-state grammar, improvement on the task (compared to randomly generated sequences) reflects implicitly acquired knowledge of this grammar (Maquet et al., 2000).

Neuroimaging was performed on three groups of subjects. One group was scanned while they were awake, both at rest and during performance of the task, providing information about which brain regions are typically activated by the task. A second group of subjects was trained on the task during the afternoon and then scanned the night after training, both while awake and during various sleep stages. Thus, group 2 was included to determine if similar brain regions were reactivated during sleep. A post-sleep session was also conducted to verify that learning had indeed occurred. Finally, a third group, never trained on the task, was scanned while sleeping to ensure that the pattern of activation present in natural sleep was different from the pattern of activation present after training.

Results showed that in REM sleep, as compared to resting wakefulness, several brain areas used during task performance were more active in trained than in nontrained subjects. These included occipital, parietal, anterior cingulate, motor and premotor cortices, and the cerebellum – all of which are consistent with the component processes involved in the visual and motor functioning involved in this task. Behavioral data confirmed that trained subjects improved significantly more across the night.

More recently, Peigneux et al. (2003), using the same task, showed that the level of acquisition of probabilistic rules attained prior to sleep was correlated with the increase in activation of task-related cortical areas during posttraining REM sleep. This suggests that cerebral reactivation is modulated by the strength of the memory traces developed during the learning episode, and as such, these data provide the first experimental evidence linking behavioral performance to reactivation during REM sleep (Peigneux et al., 2003). As with previously described animal studies (Datta, 2000), these findings suggest that it is not simply experiencing the task that modifies sleep physiology, but the process of memory consolidation associated with successful learning of the task.

These results support the hypothesis that implicit/procedural memory traces in humans can be reactivated during REM sleep, and that this reactivation is linked to improved consolidation. Indeed, looking a bit more closely at the literature, human REM sleep has also been linked to memory for complex logic games, foreign language acquisition, and to intensive studying (Smith, 2001). It is interesting that these more complex conceptual–procedural tasks often show REM sleep relationships, while more basic procedural tasks benefit mainly from NREM sleep. In order to understand these differences in sleep stage correlations, it is helpful to draw on a proposal by Greenberg and Pearlman (1974), who suggested that habitual reactions may be REM sleep-independent, while activities involving the assimilation of unusual or unrelated information require REM sleep for optimal consolidation. Such a distinction would support Pearlman's suggestion that simpler tasks are learned without a REM sleep dependency, while the learning of more complex tasks is dependent on posttraining REM sleep (Pearlman, 1979; Greenberg and Pearlman, 1974).

The above findings provide encouraging evidence that sleep-based processes can aid in procedural memory consolidation, not only for basic forms of sensory and motor memory in humans, but for complex procedural and conceptual knowledge as well. Moreover, it argues that the consolidation of familiar skills, or those that are similar to other well-learned skills, may be reliant on NREM sleep stages (particularly stage 2 NREM sleep), whereas REM sleep may be required for the integration of new concepts or skills with pre-existing information that is already stored in memory. This is an important question that warrants future investigation.

Although much remains to be understood about the precise relationship of specific sleep stages to different procedural memory processes, we can say with confidence that sleep generally aids in the consolidation of implicit and procedural forms of memory. Evidence in support of this relationship is now so overwhelming that strong positions to the contrary will, at minimum, have to be revised (Vertes and Eastman, 2000; Siegel, 2001).

## 2.35.6 Episodic Memory

We turn next to the relationship between sleep and the consolidation of episodic memories. Interest in this relationship can be traced back to a landmark study by Jenkins and Dallenbach (1924), which showed that a period of sleep led to better retention of nonsense syllables than an equivalent period of wakefulness. They interpreted this work to mean that sleep, being an inactive state, transiently protected memory from interference, whereas reduction of recall during wakefulness was due to interference.

> "The results of our study as a whole indicate that forgetting is not so much a matter of the decay of old impressions and associations as it is a matter of interference, inhibition, or obliterations of the old by the new" (Jenkins and Dallenbach, 1924: p. 612).

This interpretation struck a serious blow to the then dominant trace decay theory of forgetting, which posited that the simple passage of time was responsible for forgetting.

Nonetheless, the fact that memories were protected during sleep led to increased interest in the topic (particularly among interference theorists), and Jenkins and Dallenbach's (1924) finding was quickly replicated in better-controlled studies (e.g. Lovatt and Warr, 1968; Benson and Feinberg, 1977). Researchers began to wonder if sleep was actively promoting memory formation, rather than simply reducing interference. Moreover, they began to hypothesize that some types of sleep played a bigger role in episodic memory consolidation than others (The relationship between sleep and the consolidation of semantic memory has received scant attention to date, although see Stickgold et al. (1999) and Brualla et al. (1998) for evidence of semantic memory processing during sleep.).

After the discovery of REM sleep by Aserinsky and Kleitman (1953), the prevailing hypothesis – inspired by psychoanalytic theory – was that memory content would show up in REM sleep, because this was the only stage of sleep in which dreams were thought to occur. (It is now clear that dreams and other types of mental content can occur in all sleep stages, including SWS (Foulkes, 1966; see also Payne and Nadel, 2004)). It made a great deal of intuitive sense that REM sleep should be the stage involved in the reprocessing and consolidation of episodic memories, because, as noted above, the brain during REM sleep is intensely active and looks like it is engaging in some sort of cognitive processing.

This hypothesis was initially supported by several REM sleep-deprivation studies, which showed that such deprivation interfered with memory for prose passages (Empson and Clarke, 1970) and increased the time interval over which memories remained fragile and susceptible to electroconvulsive shock (Fishbein et al., 1971). However, as summarized in Smith (2001), REM deprivation studies in humans provided mixed results on the whole (Chernik, 1972) (see Johnson et al., 1974; Lewin and Glaubman, 1975), which may not be surprising given that sleep deprivation suffers from many confounds, including disrupted natural sleep, decreased levels of arousal and motivation, and increased levels of stress (Maquet, 2001). The stress hormone cortisol, for example, often impairs memory at high levels but can facilitate some aspects of memory at low to moderate levels (Payne and Nadel, 2004; Payne et al., 2004).

Seeking to avoid the confounds inherent in sleep deprivation studies, Ekstrand and colleagues developed a procedure that attempted to isolate SWS, which is prevalent early in the night, from REM sleep, which is maximal late in the night (see 'Stages of sleep' section above). These researchers were thus the first to systematically investigate the impact of different sleep stages on memory performance while controlling for the unspecific effects of REM sleep deprivation. Their findings implicated NREM, particularly stage 4 SWS, as the most beneficial sleep stage for episodic memory consolidation. Yaroush et al. (1971) required subjects to study a paired-associates list just before bedtime. Half of the subjects were awakened after 4 h of early sleep (dense in SWS) and tested for recall. The other half were allowed to sleep for 4 h prior to awakening; they then studied the list and returned to sleep for another 4 h late in the night (REM-rich sleep) before being awakened to recall the word pairs. A third group of subjects were trained during the day and returned 4 h later for the recall test. The early night group remembered more of the words than either the late night or wake groups in several tests of memory (paced and unpaced tests, matching, and relearning tests), suggesting that early sleep, rich in SWS, benefited episodic memory (Yaroush et al., 1971).

In a follow up-study, Barrett and Ekstrand (1972) replicated this effect while attempting to control for circadian differences. Here, all subjects were required to learn and recall at the same time of day; the retention interval was always between 3.00 a.m. to 7.00 a.m. One group remained awake until training at 3.00 a.m., slept for 4 h, and then were awakened at 7.00 a.m. for testing. Another group arrived in the lab at 10.00 p.m., slept for 4 h prior to training, awakened at 2.50 a.m. to train, returned to sleep for another 4 h and then awakened for testing at 6.50 a.m.. As in the Yaroush et al. (1971) study, recall of word pairs was better in the first-half sleep condition than in either the second-half sleep or wake conditions, thus replicating the early sleep effect while controlling for time of day (Barrett and Ekstrand, 1972).

Fowler et al. (1973) replicated the early sleep effect, this time in the sleep laboratory, where they showed that SWS was indeed most prevalent early in the night (first-half of sleep), while REM was maximal late in the night (second-half of sleep) in spite of the experimental awakenings. The authors pointed out that their findings were not easy to reconcile with an interference theory of forgetting. Subjects in the first and second half of night conditions slept for equivalent amounts of time during the retention interval, so simple protection against interference should have been equal in both groups. Unless one wanted to argue that dreaming is as much an interfering factor as a waking mental activity (and this remains to be determined), it seemed that early-night SWS, and perhaps particularly stage 4 sleep, was most important for episodic memory consolidation (Fowler et al., 1973).

More than 20 years later, Born and colleagues revived this procedure (Plihal and Born, 1997; Plihal and Born 1999a,b). In the first of their studies (Plihal and Born, 1997), both episodic (recall of semantically related paired associates) and procedural (performance on a mirror tracing task) memory were assessed within the same subjects. Participants were trained to criterion on both tasks and then retested after 3-h retention intervals, containing either early or late nocturnal sleep. The results showed that memory improvements were greater after sleep than after a corresponding period of wake, but more importantly, the different periods of sleep seemed to support consolidation of different types of memory. Recall of paired associates improved more after 3 h of early sleep rich in SWS than after 3 h of late sleep rich in REM, or after a 3-h period of wake. Conversely, mirror tracing improved more after 3 h of late, REM-rich sleep than after 3 h spent either in early sleep or awake.

In a related study, Plihal and Born (1999a) examined different measures of episodic and implicit memory in order to separate the effects of type of material (verbal vs. nonverbal) from type of memory (episodic vs. procedural). Thus, a nonverbal episodic memory task (spatial rotation) and a verbal implicit task (word-stem priming) were used in the same early versus late night sleep procedure, and the findings mirrored the previous results. Compared to wake, recall of spatial memory was enhanced after early retention sleep but not late retention sleep, while priming was enhanced more after late than early retention sleep.

It is important to note that this early-/late-night sleep procedure suffers not only from confounds associated with sleep deprivation, but also from an incomplete separation of REM and NREM sleep. Early sleep is an imperfect proxy for SWS, and similarly, late sleep is an imperfect proxy for REM sleep. SWS does appear in the second half of the night, and REM appears in the first half of the night, and thus one cannot exclude the possibility that REM and SWS during these periods contributed to the noted consolidation effects. Moreover, the distribution of stage 2 NREM sleep is not entirely equal in both halves of the night. Thus, one cannot examine early versus late sleep and make definitive conclusions about SWS versus REM sleep.

In addition, SWS is tested by training subjects before they go to sleep (at around 10.00 or 11.00 p.m.) and then awakening them 3 h later for memory testing. REM sleep, on the other hand, is tested by awakening subjects to train in the middle of the night. These subjects then return to sleep before being awakened 3 h later for memory testing. Training in the middle of the night may well be less effective than training that occurs before subjects have slept at all, which means that the lack of improvement seen after REM awakenings in some experiments may be confounded; what looks like a failure to consolidate may simply reflect a difference in the quality of encoding and degree of attentional resources available for the task after being awakened in the middle of the night as opposed to in the evening prior to sleep. Finally, control groups that are awake for similar periods in the night are acutely sleep deprived, limiting the validity of the comparisons. Therefore, while the value of this creative procedure is that it manipulates sleep stages experimentally, a number of problems limits the clear interpretation of these findings.

In spite of these problems, two neuroimaging investigations of episodic memory consolidation have also suggested an important role for SWS. The first of these investigated performance on a hippocampally dependent virtual maze task (Peigneux et al., 2004). Daytime learning of the task was associated with hippocampal activity. Then, during posttraining sleep, there was a reemergence of hippocampal activation, and it occurred specifically during SWS. The most compelling finding, however, is that the increase in hippocampal activation seen during posttraining SWS was proportional to the amount of improvement seen the next day (see also Peigneux et al., 2003 described above). This suggests that the re-expression of hippocampal activation during SWS reflects the off-line reprocessing of spatial episodic memory traces, which in turn leads to the plastic changes underlying the improvement in memory performance seen the next day.

The second study (Takashima et al., 2006) investigated the time course of episodic memory consolidation across 90 days. Subjects studied 360 photographs of landscapes and were then tested on subsets of the photographs either after a nap the same day, or after 2, 30, or 90 days. Prior to each test, subjects studied 80 new pictures, and then were tested on 80 of the original pictures and the 80 new ones, as well as 80 pictures they had never seen before. All memory retrieval sessions occurred during fMRI scanning.

Following the initial 90-min nap, stage 2 sleep was positively correlated with successful recall of both remote and recent items, indicating a nonspecific benefit of stage 2 NREM sleep on episodic memory. This is an intriguing finding, given that stage 2 is where sleep spindles are most prominent (see the section titled ‘Electrophysiological signatures’). Slow-wave sleep, on the other hand, was correlated only with memory for remote (but not recent) items. Because performance on remote items increased with longer SWS duration, but performance for recent items did not, the effect on memory performance for remote items cannot be explained by a general effect of SWS on memory retrieval processes. The authors also point out that this brief period of SWS may have had an even longer-lasting effect on memory, because there was a linear relationship between the amount of SWS during the nap and recognition memory performance after both 2 and 30 days, whereas there continued to be no such correlation for recent items. This finding is striking, given that this was a nap rather than a full night of sleep, and that only 15 of the 24 subjects reached SWS. Finally, longer SWS durations led to decreases in hippocampal activation when remote items were successfully retrieved (it should be noted that while this finding appears to support traditional consolidation theory (Squire and Cohen, 1984), the hippocampus remained active during successful retrieval throughout the study (up to the last test at 90 days), suggesting that episodic memories may never become completely independent of the hippocampus (Nadel and Moscovitch, 1997; Moscovitch et al., 2006). These findings strongly suggest that episodic memories can undergo initial consolidation within a rather short time frame and that this consolidation is promoted by SWS.

In another nap study, Tucker et al. (2006) found that naps containing only NREM sleep enhanced declarative memory for word pairs. Performance on episodic (paired-associates) and procedural (mirror tracing) memory tasks were tested 6 h after training, either with or without an intervening nap. While there was no difference between nap and wake subjects on the procedural memory task, the nap subjects performed significantly better on the paired associate task relative to the subjects who remained awake

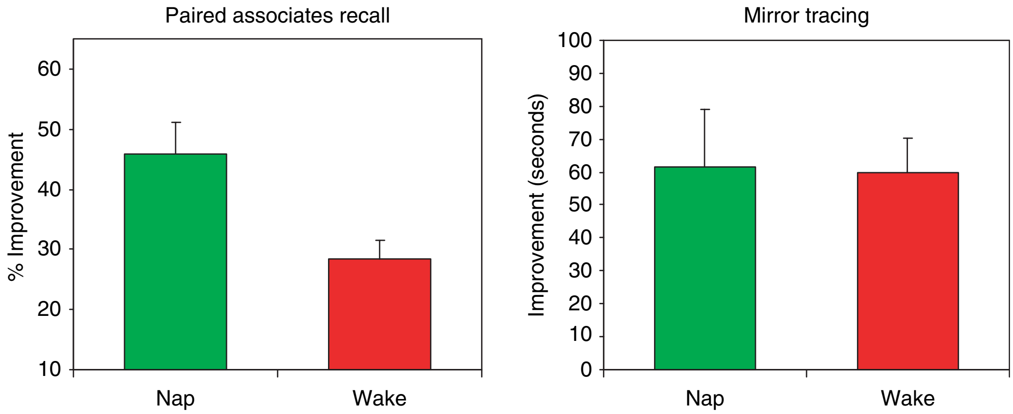


**Figure 7** A brief daytime nap benefits episodic memory. Note that the nap (which did not contain REM sleep) benefited episodic, but not procedural, memory. From Tucker MA, Hirota Y, Wamsley EJ, et al. (2006) A daytime nap containing solely non-REM sleep enhances declarative but not procedural memory. *Neurobiol. Learn. Mem.* 86(2): 241–247.

(**Figure 7**). Subjects in the nap condition also showed a weak correlation between improved recall and the amount of SWS in the nap, further supporting the relationship between episodic memory and SWS (Tucker et al., 2006). It will be interesting to see a follow-up study in which the contribution of REM sleep physiology is assessed.

These results should not be taken to mean that REM sleep mediates the consolidation of procedural memories, whereas SWS mediates the consolidation of episodic memories. Matters are clearly not so simple. Recall that improvement on a visual discrimination task depended on SWS as well as REM (Gais et al., 2000), and improvement on a motor task correlated with stage 2 NREM sleep (Smith and MacNeill, 1994). Moreover, emotionally charged episodic memories may rely on REM sleep for their consolidation (see 'Emotional episodic memory' section below).

There are two possible interpretations of these apparent contradictions. First, the sleep stage dependency of these various memory tasks may depend on aspects of the task other than simply whether they are episodic or procedural, perhaps depending more on the intensity of training, the emotional salience of the task, or even the manner in which information is encoded (e.g., deep versus shallow encoding or implicit versus explicit). The second possibility involves an inherent oversimplification in correlating performance improvements with sleep stages as they are classically defined. Indeed, mounting evidence points to several electrophysiological, neurotransmitter, and neuroendocrine mechanisms that may underlie these effects and which do not necessarily correlate with any single sleep stage (see section below), and sleep staging, as it has been defined for 40 years, may not capture all of the key elements that lead to memory consolidation enhanced by sleep.

At an even more basic level, none of the verbal episodic memory studies described above demonstrated that a full night of sleep can produce the kinds of benefits seen following a half-night of sleep or an afternoon nap. The idea of early SWS-rich sleep, but not late REM-rich sleep, being linked to improvements in episodic memory performance, for example, loses much of its interest if these early-night benefits were lost across the second half of the night, such that they would not be available the following day.

Fortunately, several very recent reports dispel this concern (e.g., Ellenbogen et al., 2006; Gais et al., 2006b). These studies demonstrate lasting benefits of a full night of sleep on episodic memory. For example, Ellenbogen et al. (2006) showed that a full night of sleep not only strengthened memory for unrelated paired associates, but also made these memories more resistant to interference than an equivalent period of time spent awake.

Using a classic AB-AC interference paradigm (Barnes and Underwood, 1959), subjects first learned a list of paired associates, $A_iB_i$. After either a 12-h period including a night with 7–8 h of sleep, or an equivalent 12-h period of wakefulness during the day, half of the subjects in each group recalled the previously learned word pairs (cued recall). The other half learned a new list of paired associates, $A_iC_i$, before being tested for recall of the original list. To control for circadian effects and to demonstrate that the effects of sleep persist, an additional group of subjects was trained at the same circadian time as the sleep group (9.00 p.m.), and tested 24 rather than 12 h later.

While sleep provided modest protection against memory deterioration even in the absence of interference training, it provided a large and dramatic protection against post-sleep interference, and this benefit was sustained throughout the subsequent waking day (**Figure 8**). Thus, memories after sleep were highly resistant to interference and remained resistant across the subsequent day, demonstrating significantly better recall after 24 h than memories encoded in the morning and tested just 12 h later, without sleep. This study suggests that sleep does more than simply protect memories from interference while asleep: sleep stabilizes memories, making them resistant to future interference during the subsequent wake period.

A study by Gais et al. (2006b) provides additional evidence that sleep does more than protect memories against interference (see Wixted, 2004 for a full review of the interference argument). Subjects learned English–German vocabulary lists in the morning (8.00 a.m.) or in the evening (8.00 p.m.) and were tested immediately via cued recall to establish a baseline memory retention score. They were then retested after 24 or 36 h, either at the same circadian time or at a different circadian time (i.e., subjects trained at 8.00 a.m. and were retested at 8.00 p.m. or vice-versa). Subjects went to sleep either soon after training and initial testing (approximately 3 h in the 8.00 p.m. training condition) or after a significant delay (approximately 15 h in the 8.00 a.m. training condition).

Subjects who slept soon after training (and were retested either 24 or 36 h later) performed better on the retest session, suggesting that a night of sleep shortly after training benefited their performance on the task. In a second experiment, subjects were similarly trained in the evening either prior to sleep or to a night of sleep deprivation. Sleep-deprived subjects were allowed to sleep the following day, where they made up much of their lost sleep. However, the deprived subjects did not sleep until 10 h after training, whereas control subjects went to sleep a mere 3 h after training. In both conditions, recall testing took place 48 h after initial learning, again in the evening, to allow for recovery sleep in the deprivation condition. Although no differences emerged in the initial test on the first evening, there was a clear deficit after a night of sleep deprivation. Subjects remembered more words when they slept the night following training than when they remained awake, thus providing further evidence that sleep benefits memory consolidation. Importantly, both the 24 h groups (a.m. and p.m.

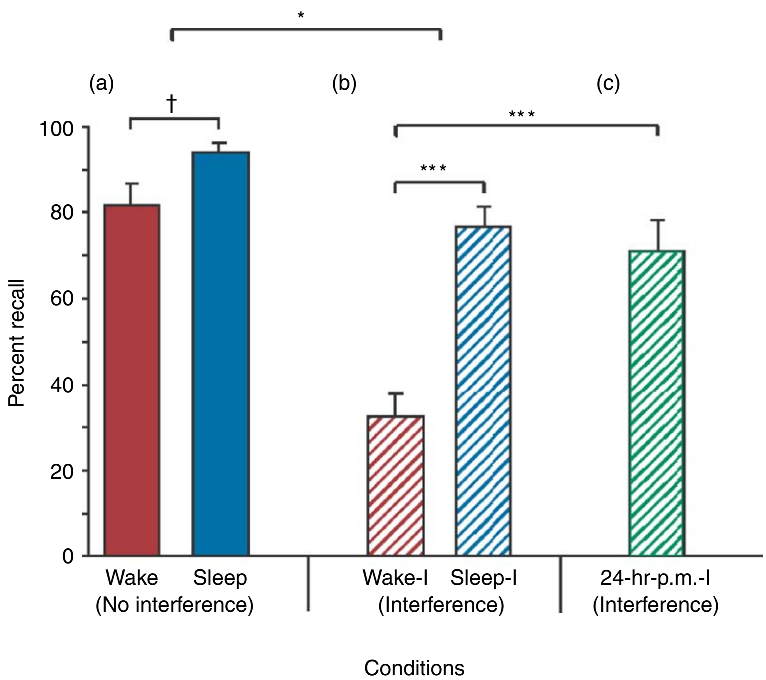


**Figure 8** Sleep makes memory resistant to interference. Note that this beneficial effect of sleep was seen after 12 nighttime hours including sleep and remained 24 hours later. From Ellenbogen JM, Hulbert JC, Stickgold R, et al. (2006a) Interfering with theories of sleep and memory: Sleep, declarative memory, and associative interference. *Current Biology* 16(13): 1290–1294.

training) underwent identical amounts of waking interference, as did the two 48-h groups (controls and sleep-deprived), which strongly suggests that the sleep benefits cannot be explained by a decrease in waking interference.

Thus, it appears quite unlikely that sleep merely offers a permissive, interference-free environment for memory consolidation. It is plausible that sleep also activates unique neurobiological processes that play an active role in consolidation (for a recent review, see Ellenbogen et al., in press). This would suggest that there are sleep-specific neural processes that contribute to memory consolidation – an argument we review in the section titled 'Electrophysiological signatures'.

### 2.35.6.1 Emotional Episodic Memory

Sleep also appears to contribute to the consolidation of emotional episodic memories. This is interesting in light of the many early studies that demonstrated slow, time-dependent improvements in emotional memory, where memory for emotionally laden events, or emotional aspects of complex events, often continued to improve over days and even weeks (Kleinsmith and Kaplan, 1963; Kleinsmith et al., 1963; Kleinsmith and Kaplan, 1964). While it is well known that memories of emotional events are encoded and subsequently persist more strongly than memories for neutral events (McGaugh, 2000; Kensinger, 2004), only recently has sleep's contribution to this apparent consolidation effect been examined (Hu et al., 2006; Wagner et al., 2001).

Hu et al. (in press) examined the impact of a full night of sleep on both axes of emotional affect – valence (positive/negative) and arousal (high/low), across both remember and know measures of memory for pictures. Results showed that a night of sleep improved memory accuracy for emotionally arousing pictures relevant to an equivalent period of daytime wakefulness, but only for know judgments. No differences were observed for remember judgments. Moreover, memory bias changed across a night of sleep relative to wake, such that subjects became more conservative when making remember judgments, especially for emotionally arousing pictures. No bias differences were observed for know judgments between sleep and wake. These findings provide further evidence that the facilitation of memory for emotionally salient information may preferentially develop during sleep. Whether these effects emerge primarily after REM-rich, late night sleep, as in Wagner et al. (2001) (discussed in the section titled 'Neurohormones and neurotransmitters'), remains to be investigated. Nonetheless, the enhancing impact of sleep on the remembrance of emotional episodic information is becoming increasingly clear.

## 2.35.7 Electrophysiological Signatures

But what is it about sleep that leads to memory consolidation? Several electrophysiological signatures of sleep, recorded in animals with cortical electrodes as well as in the human EEG, reflect synchronized oscillatory patterns of neuronal activity in the cortex that may actively promote memory consolidation. There are still relatively few studies examining these proposed neurophysiological mechanisms. However, we expect the number to increase dramatically in the near future, and so we review what is currently known here.

### 2.35.7.1 Sleep Spindles

Sleep spindles are one example of such a mechanism. Sleep spindles are bursts of coherent brain activity visible on the EEG, which are most evident during stage 2 sleep. They consist of brief 11- to 16-Hz waves lasting 0.5–1.5 s. In animals, the initiation of cortical sleep spindles tends to occur with high-frequency (~200 Hz) ripples that ride on hippocampal sharp waves in NREM sleep (Siapas and Wilson, 1998). This co-occurrence of hippocampal sharp waves and cortical spindles may underlie the integration of information between the hippocampus and neocortex as memories are consolidated during sleep (Buzsáki, 1996).

In support of this hypothesis, several human studies have shown a correlation between hippocampally dependent episodic learning and cortical sleep spindles. In one such study (Gais et al., 2002), subjects studied a long list of unrelated word pairs 1 h prior to sleep, on two separate occasions, at least a week apart. In one case, they were instructed to imagine a relationship between the two nominally unrelated words, while in the other they were simply asked to count the number of letters containing curved lines in each word pair. Such instructions lead to deep, hippocampally mediated encoding and shallow, cortically mediated encoding, respectively. During the subsequent nights of sleep, subjects showed significantly higher spindle densities on the nights following deep encoding, averaging 34% more spindles in the first 90 min of sleep. Moreover, sleep spindle density was positively correlated both with immediate recall tested in the final stage of training and with recall the next morning, after sleep. Thus, those who learned better had more spindles the following night, and those with more spindles showed better performance the next morning.

These findings mirror previous observations by Meier-Koll et al. (1999), who reported a similar increase in spindles following learning of a hippocampally dependent maze task, and by Clemens et al. (2005) who found a correlation between spindle density and overnight verbal memory retention (although not between spindle density and memory for faces). Interestingly, Smith and colleagues have reported increased spindle density after intensive training on a pursuit rotor task, and after combined training on several simple procedural motor tasks (Fogel and Smith, 2006; Fogel et al., 2007). Thus, spindles might contribute to the consolidation of both explicit and implicit memories (Meier-Koll et al., 1999; Clemens et al., 2005; Fogel and Smith, 2006).

But sleep spindles also appears to correlate strongly with IQ (Bodizs et al., 2005; Schabus et al., 2006), and it can thus be difficult to discern whether high spindle content correlates with overnight improvement in memory *per se*, or whether both reflect correlations with IQ. While this is not problematic when repeated measures or factorial designs compare nights with and without preceding memory encoding, the correlation with IQ confounds correlational studies that show more posttraining spindles in subjects who subsequently show better recall.

### 2.35.7.2 Slow Waves

Given the evidence for early night facilitation of episodic memory recall (e.g., Plihal and Born, 1997, 1999a,b), it is not surprising that neurophysiologic markers associated with slow-wave sleep (SWS) have also been implicated in memory consolidation. Slow-wave rhythms, including both classical delta activity (1–4 Hz), and the more recently characterized cortical slow oscillations (<1 Hz) increase as humans pass into SWS. Indeed, these cortical slow oscillations are now considered a hallmark of SWS (Steriade and Timofeev, 2003). Such slow oscillatory activity in neuronal networks allows distant ensembles to become synchronized in rats and has been hypothesized to facilitate the binding and consolidation of memories that are dispersed across distant brain regions (Buzsáki and Draguhn, 2004).

Cortical slow oscillations have recently been observed in humans in conjunction with increased EEG coherence. EEG coherence is a large-scale measure of the coactivation of distant brain regions. Molle et al. (2004) recently showed that increased EEG coherence, which was strong during the memorization of word pairs, reappeared with cortical slow oscillations during subsequent slow wave sleep. Interestingly, while there were only marginal increases in coherence when measured over all NREM sleep, this coherence was dramatically increased when the analysis was time-locked to the occurrence of cortical slow oscillations (Molle et al., 2004).

This finding suggests that slow oscillations are important for the reprocessing of memories during sleep, a conclusion that is based on two assumptions. First, it assumes that high coherence between EEG signals from different sites on the scalp reflect an increased interplay between the underlying neuronal networks, and second, it assumes that efficient encoding of associations in episodic memory is facilitated by the large-scale synchrony of cortical neuronal activity measured by EEG coherence. Given these assumptions, the finding suggests that cortical slow oscillations may be of particular functional significance for the reprocessing of newly acquired associative memories during human SWS.

Slow oscillations also appear to exert a grouping influence over spindle activity. Molle et al. (2002) examined the temporal dynamics between spindle activity and slow oscillations in the human EEG during NREM stage 2 and SWS. They found that during human SWS, rhythmic activity in the spindle frequency range correlated with periods of slow oscillations. They also showed that discrete spindles identified during NREM stage 2 sleep coincided with the depolarizing portion of the cortical slow oscillations and were preceded by pronounced hyperpolarizing half-waves (Molle et al., 2002). These results suggest that slow rhythmic depolarizations and hyperpolarizations in cortical neurons might alternately drive and inhibit thalamically generated spindle activity, thereby contributing indirectly to memory consolidation through their regulation of spindles.

There are two distinct mechanisms by which spindles might provide the conditions necessary to induce long-term synaptic changes. Relevant cortical neural networks may be selectively activated during spindle activity as a result of previous learning, and, in turn, this activation may induce activity in, and thus modification of, related networks within the hippocampal complex. Alternatively, hippocampal activity driven by recent learning might selectively prime relevant cortical networks, which would then be activated and modified during subsequent sleep spindles (Siapas and Wilson, 1998). Either way, the spindles themselves may induce long-term synaptic changes in the neocortex.

Sleep spindles and slow oscillations represent promising candidate mechanisms for sleep-dependent memory consolidation, but it is important to note that a causal role for these electrophysiological signatures remains to be demonstrated. Nevertheless, they provide preliminary support, in humans, for the idea that the hippocampus and neocortex cooperate to integrate new information into long-term memory during sleep (Buzsáki, 1996).

### 2.35.7.3 Hippocampal and Cortical Replay

This hippocampal–neocortical communication paradigm is important, because it is intimately intertwined with theories of memory consolidation. New memories are at least initially dependent on connections between medial temporal and neocortical regions, and increased communication between these regions after training on a memory task may reflect consolidation of these recently acquired memories. A growing literature demonstrates precisely these effects in animals, where hippocampally dependent learning leads to post-training reactivations in brain areas involved in memory processing.

In the earliest studies, Pavlides and Winson (1989) demonstrated spontaneous neuronal replay of task-specific firing patterns during posttraining sleep, with individual hippocampal place cells that discharged during spatial exploration increasing their firing rates during subsequent sleep. Recording from large ensembles of place cells in the CA1 field of the hippocampus, Wilson and McNaughton (1994) showed that pairs of cells that fired together as rats passed through specific locations in an open field also fired together during subsequent SWS. This cellular activity during sleep mimicked the firing patterns seen when the task was performed, suggesting that information acquired during wake is re-expressed during sleep and that this reactivation forms a neurophysiological substrate of sleep-dependent memory consolidation (Pavlides and Winson, 1989; Wilson and McNaughton, 1994).

Since then, numerous studies have reported neuronal replay during both SWS (Skaggs and McNaughton, 1996; Kudrimoti et al., 1999; Lee and Wilson, 2002) and REM sleep (Poe et al., 2000; Louie and Wilson, 2001). Interestingly, the replay of temporal patterns of activity during SWS occurs on a time scale 20 times faster than the previous waking pattern (Lee and Wilson, 2002), while during REM it occurs in close to real time, averaging just 40% slower than in wake (Louie and Wilson, 2001).

The finding, discussed above (Siapas and Wilson, 1998), of temporal correlations during SWS between hippocampal sharp-wave/ripples and the initiation of individual prefrontal sleep spindles, along with similar correlations between the hippocampus and somatosensory cortex (Sirota et al., 2003) provides a mechanism by which such neuronal replay could lead to consolidation in both hippocampal and cortical networks.

### 2.35.7.4 Theta Rhythm

There is evidence in both humans and animals that theta frequency (4–7 Hz) oscillations are associated with enhanced learning and memory during the waking state (Bastiaansen and Hagoort, 2003), and it has been suggested that the integration of information within hippocampal and neocortical circuits may be mediated by theta activity. Although there is little theta activity during SWS, it is at waking levels during REM sleep, when hippocampal cell discharge is modulated at the theta frequency. This theta activity may aid memory reprocessing during REM sleep by enabling information to flow from the neocortex (through the superficial layers of the entorhinal cortex) into the hippocampus, where it can reverberate within hippocampal circuitry (i.e., replay). In contrast, during the sharp-wave and ripple activity of SWS, information may flow in the opposite direction, out of the hippocampus and back to the neocortex (through deep layers of the entorhinal cortex Buzsáki, 1996; Buzsáki, 1998), thus allowing information to flow throughout the complete neocortex–hippocampal circuit. Indeed, it has been proposed that high levels of the neurotransmitter acetylcholine and the neurohormone cortisol during REM sleep, and low levels during SWS, might modulate communication between hippocampus and neocortex as memories undergo consolidation (Payne and Nadel, 2004). In this view, as in others (Giuditta et al., 1995;Ficca et al., 2000), both SWS and REM sleep are thought to contribute to the consolidation of episodic memories. In addition, for emotional memory processing, cooperative theta oscillations between hippocampal and amygdala regions during REM sleep may play an important role as well (Pare et al., 2002).

## 2.35.8 Neurohormones and Neurotransmitters

Many modulatory neurotransmitters contribute to memory formation. Acetylcholine, however, has received the most attention by the sleep community to date, most likely because it is critically involved in control of the NREM/REM cycle, and because it is present at particularly high levels during REM sleep and low levels during SWS (Hobson et al., 1998).

Acetylcholine, although mainly involved in memory encoding, appears to also play a role in the flow of information between memory systems during different stages of sleep. According to a model by Hasselmo (1999), acetylcholine inhibits feedback loops both within the hippocampus and between the hippocampus and neocortex. As a result, the high cholinergic activity seen during wakefulness minimizes consolidation and promotes encoding of new episodic memories, whereas the low cholinergic activity in SWS blocks new input and supports the replay of recently encoded information in the hippocampus. This replay may then lead to integration of this information within hippocampal and neocortical memory stores (Buzsáki, 1996; Hasselmo, 1999; Payne and Nadel, 2004).

To investigate the role of acetylcholine in the consolidation of episodic memory during sleep, Gais and Born (2004b) trained subjects on a list of paired associates, as well as a mirror tracing task, before 3 h of SWS-rich nocturnal sleep or wakefulness during which they received a placebo or an infusion of the cholinesterase inhibitor physostigmine (which increases cholinergic tone). When tested after 3 h of sleep, recall on the paired-associates task was impaired in the physostigmine group, while procedural memory performance was unaffected (Gais and Born, 2004b). This provides initial support for Hasselmo's (1999) model and suggests that the inhibition of cholinergic activity during SWS is critical for sleep-based episodic memory consolidation.

As with neurotransmitters, hormonal fluctuations across the sleep cycle may also help to explain why different sleep stages contribute differentially to the consolidation of episodic memories. Activation of the neuroendocrine hypothalamic–pituitary–adrenocortical (HPA) system, for instance, results in the release of the stress hormone cortisol from the adrenal glands. Cortisol then feeds back onto the brain, where the hippocampus and frontal cortex, arguably two of the most critical memory regions, contain the highest number of cortisol receptors in humans (Lupien and Lepage, 2001). Several studies have demonstrated cortisol-induced memory impairments with episodic memory tasks during wake (Kim and Diamond, 2002; Payne et al., 2002; Payne et al., 2006). Intriguingly, cortisol levels are at their lowest during early nocturnal sleep, while achieving a diurnal maximum during late night sleep (Plihal and Born 1999b; Born and Wagner, 2004).

Plihal and Born (1997, 1999a) have thus argued that the circadian suppression of cortisol release early in the night makes this SWS-rich sleep an ideal physiological environment for episodic memory consolidation. Naturally low cortisol levels during early sleep promote more efficient consolidation of episodic memories than is seen during late, REM-rich sleep, when cortisol levels are high. In support of this view, Plihal and Born (1999b) showed that artificially elevating cortisol levels during early sleep eradicated the normal episodic memory benefit seen during this period, suggesting that the salubrious environment provided by early sleep is a result, at least in part, of the naturally low levels of cortisol during this time.

Cortisol levels in the Plihal and Born (1999b) study were elevated to levels similar to those typically seen in response to mild to moderate stressors, that are sufficient to disrupt episodic memory function during wakefulness (Kirschbaum et al., 1996; de Quervain et al., 2003; de Quervain, 2006).

In another study suggestive of a cortisol-related influence on memory consolidation (Wagner et al., 2001), memory for emotionally laden narrative material was facilitated after late night, REM-rich sleep periods. At first blush, this result seems to contradict the evidence reviewed in the section titled 'Emotional episodic memory', which demonstrated that late night REM sleep does not support episodic memory consolidation, perhaps due to high cortisol levels. Yet studies have consistently shown that cortisol facilitates memory for emotional episodic materials, while impairing closely matched neutral materials during wakefulness (Buchanan and Lovallo, 2001; Payne et al., 2006). Given the role of cortisol in enhancing emotional episodic information, the late-night enhancement of emotional memory in this study is not surprising.

In addition to cortisol, other hormones (e.g., growth hormone) are known to impact memory function in the waking state, and also vary across sleep, suggesting that they might contribute to sleep-based memory consolidation. Although initial studies of growth hormone have failed to find such an effect (Gais et al., 2006), further investigation of the neurochemistry underlying the relationship between sleep and memory consolidation is a productive avenue for future research. Indeed, it seems especially important to forge ahead into precisely this neuromodulatory realm, where the chemical basis of the sleep/memory consolidation connection is examined.

## 2.35.9 Concluding Comments

Over the past 10 years, the field of sleep and memory has grown exponentially, with reports of sleep–memory interactions emerging from myriad disciplines, ranging form cellular and molecular studies in animals to behavioral and neuroimaging studies in humans. In our view, sleep undoubtedly mediates memory processes, but the way in which it does so remains largely unknown. This makes the future of the field truly exciting, but also challenging. Much remains to be done, from uncovering the mechanisms of brain plasticity that underlie sleep-based memory processing, to untangling the complex relationship between the various sleep stages and types of memory. In so doing, memory researchers may find a field in which some of the more recalcitrant problems of basic memory research can also be answered.

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## References

Amzica F and Steriade M (1995) Disconnection of intracortical synaptic linkages disrupts synchronization of a slow oscillation. *J. Neurosci.* 15: 4658–4677.

Aserinsky E and Kleitman N (1953) Regularly occurring periods of ocular motility and concomitant phenomena during sleep. *Science* 118: 273–274.

Atienza M, Cantero JL, and Dominguez-Marin E (2002) The time course of neural changes underlying auditory perceptual learning. *Learn. Mem.* 9(3): 138–150.

Atienza M, Cantero JL, and Stickgold R (2004) Post-training sleep enhances automaticity in perceptual discrimination. *J. Cogn. Neurosci.* 16: 53–64.

Barnes JM and Underwood BJ (1959) Fate of first-list associations in transfer theory. *J. Exp. Psychol.* 58: 97–105.

Barrett TR and Ekstrand BR (1972) Effect of sleep on memory. 3. Controlling for time-of-day effects. *J. Exp. Psychol.* 96(2): 321–327.

Bastiaansen M and Hagoort P (2003) Event-induced theta responses as a window on the dynamics of memory. *Cortex* 39(4–5): 967–992.

Benington JH and Frank MG (2003) Cellular and molecular connections between sleep and synaptic plasticity. *Prog. Neurobiol.* 69(2): 71–101.

Benson K and Feinberg I (1977) The beneficial effect of sleep in an extended Jenkins and Dallenbach paradigm. *Psychophysiology* 14(4): 375–84.

Bodizs R, Kis T, Lázár AS, et al. (2005) Prediction of general mental ability based on neural oscillation measures of sleep. *J. Sleep Res.* 14(3): 285–292.

Born J and Wagner U (2004) Memory consolidation during sleep: Role of cortisol feedback. *Ann. N. Y. Acad. Sci.* 1032: 198–201.

Brualla J, Romero MF, Serrano M, and Valdizan JR (1998) Auditory event-related potentials to semantic priming during sleep. *Electroencephalogr: Clin. Neurophysiol.* 108(3): 283–290.

Buchanan TW and Lovallo WR (2001) Enhanced memory for emotional material following stress-level cortisol treatment in humans. *Psychoneuroendocrinology* 26(3): 307–317.

Buzsáki G (1996) The hippocampo-neocortical dialogue. *Cereb. Cortex* 6: 81–92.

Buzsáki G (1998) Memory consolidation during sleep: A neurophysiological perspective. *J. Sleep Res.* 7(Suppl 1): 17–23.

Buzsáki G and Draguhn A (2004) Neuronal oscillations in cortical networks. *Science* 304(5679): 1926–1929.

Cahill L (2000) Neurobiological mechanisms of emotionally influenced, long-term memory. *Prog. Brain Res.* 126: 29–37.

Cahill L and McGaugh JL (1996) Modulation of memory storage. *Curr. Opin. Neurobiol.* 6(2): 237–242.

Chernik D (1972) Effect of REM sleep deprivation on learning and recall by humans. *Percept. Motor Skills* 34: 283–294.

Clemens Z, Fabó D, and Halász P (2005) Overnight verbal memory retention correlates with the number of sleep spindles. *Neuroscience* 132(2): 529–535.

Datta S (2000) Avoidance task training potentiates phasic pontine-wave density in the rat: A mechanism for sleep-dependent plasticity. *J. Neurosci.* 20(22): 8607–8613.

Datta S, Mavanji V, Ulloor J, et al. (2004) Activation of phasic pontine-wave generator prevents rapid eye movement sleep deprivation-induced learning impairment in the rat: A mechanism for sleep-dependent plasticity. *J. Neurosci.* 24(6): 1416–1427.

de Quervain DJ (2006) Glucocorticoid-induced inhibition of memory retrieval: implications for posttraumatic stress disorder. *Ann. N. Y. Acad. Sci.* 1071: 216–220.

de Quervain DJ, Henke K, Aerni A, et al. (2003) Glucocorticoid-induced impairment of declarative memory retrieval is associated with reduced blood flow in the medial temporal lobe. *Eur. J. Neurosci.* 17(6): 1296–1302.

Dudai Y (2004) The neurobiology of consolidations, or, how stable is the engram? *Ann. Rev. Psychol.* 55: 51–86.

Ellenbogen JM, Hulbert JC, Stickgold R, et al. (2006a) Interfering with theories of sleep and memory: Sleep, declarative memory, and associative interference. *Curr. Biol.* 16(13): 1290–1294.

Ellenbogen JM, Payne JD, and Stickgold R (2006b) The role of sleep in declarative memory consolidation: Passive, permissive, active or none? *Curr. Opin. Neurobiol.* 16(6): 716–722.
Empson JA and Clarke PR (1970) Rapid eye movements and remembering. *Nature* 227(5255): 287–288.
Fenn KM, Nusbaum HC, and Margoliash D (2003) Consolidation during sleep of perceptual learning of spoken language. *Nature* 425(6958): 614–616.
Ficca G, Lombardo P, Rossi L, et al. (2000) Morning recall of verbal material depends on prior sleep organization. *Behav. Brain Res.* 112(1–2): 159–163.
Fischer S, Hallschmid M, Elsner AL, et al. (2002) Sleep forms memory for finger skills. *Proc. Natl. Acad. Sci. USA* 99(18): 11987–11991.
Fishbein W, McGaugh JL, and Swarz JR (1971) Retrograde amnesia: Electroconvulsive shock effects after termination of rapid eye movement sleep deprivation. 172(978): 80–82.
Fogel S, Jacob J, and Smith C (2001) Increased sleep spindle activity following simple motor procedural learning in humans. *Actas Fisiol.* 7: 123.
Fogel SM and Smith CT (2006) Learning-dependent changes in sleep spindles and stage 2 sleep. *J. Sleep Res.* 15(3): 250–255.
Fogel SM, Smith CT, and Cote KA (2007) Dissociable learning-dependent changes in REM and non-REM sleep in declarative and procedural memory systems. *Behav. Brain. Res.* 180: 48–61.
Fowler MJ, Sullivan MJ, and Ekstrand BR (1973) Sleep and memory. *Science* 179(70): 302–304.
Gaab N and Paetzold M, et al. (2004) The influence of sleep on auditory learning: A behavioral study. *Neuroreport* 15(4): 731–734.
Gais S and Born J (2004a) Declarative memory consolidation: Mechanisms acting during human sleep. *Learn. Mem.* 11(6): 679–685.
Gais S and Born J (2004b) Low acetylcholine during slow-wave sleep is critical for declarative memory consolidation. *Proc. Natl. Acad. Sci. USA* 101(7): 2140–2144.
Gais S, Plihal W, Wagner U, et al. (2000) Early sleep triggers memory for early visual discrimination skills. *Nat. Neurosci.* 3(12): 1335–1339.
Gais S, Molle M, Helms K, et al. (2002) Learning-dependent increases in sleep spindle density. *J. Neurosci.* 22(15): 6830–6844.
Gais S, Hullemann P, Hallschmid M, et al. (2006a) Sleep-dependent surges in growth hormone do not contribute to sleep-dependent memory consolidation. *Psychoneuroendocrinology* 31(6): 786–791.
Gais S, Lucas B, and Born J (2006b) Sleep after learning aids memory recall. *Learn. Mem.* 13(3): 259–262.
Giuditta A and Ambrosini MV, et al. (1995) The sequential hypothesis of the function of sleep. *Behav. Brain Res.* 69: 157–166.
Graves L, Pack A, and Abel T (2001) *Sleep and memory: a molecular perspective. A* 24: 237–243.
Greenberg R and Pearlman CA (1974) Cutting the REM nerve: an approach to the adaptive function of REM sleep. *Perspect. Biol. Med.* 17: 513–521.
Hamann S (2003) Nosing in on the emotional brain. *Nat. Neurosci.* 6(2): 106–108.
Hamann SB, Ely TD, Grafton ST, et al. (1999) Amygdala activity related to enhanced memory for pleasant and aversive stimuli. *Nat. Neurosci.* 2(3): 289–293.
Hamann SB, Ely TD, Hoffman JM, et al. (2002) Ecstasy and agony: Activation of the human amygdala in positive and negative emotion. *Psychol. Sci.* 13(2): 135–141.
Hasselmo ME (1999) Neuromodulation: Acetylcholine and memory consolidation. *Trends Cogn. Sci.* 3: 351–359.
Hennevin E, Hars B, Maho C, et al. (1995) Processing of learned information in paradoxical sleep: Relevance for memory. *Behav. Brain Res.* 69: 125–135.
Hobson JA (2005) Sleep is of the brain, by the brain and for the brain. *Nature* 437(7063): 1254–1256.
Hobson JA, McCarley RW, and Wyzinski PW (1975) Sleep cycle oscillation: Reciprocal discharge by two brainstem neuronal groups. *Science* 189: 55–58.
Hobson JA, Stickgold R, and Pace-Schott EF (1998) The neuropsychology of REM sleep dreaming. *Neuroreport* 9: R1–R14.
Huber R, Ghilardi MF, Massimini M, et al. (2004) Local sleep and learning. *Nature* 430(6995): 78–81.
Hu P, Stylos-Allan M, and Walker M (2006) Sleep facilitates consolidation of emotional declarative memory. *Psychol. Sci.* 17: 891–898.
Jenkins JG and Dallenbach KM (1924) LXXII. Obliviscence during sleep and waking. *Am. J. Psychol.* 35: 605–612.
Johnson LC, Naitoh P, Moses JM, et al. (1974) Interaction of REM deprivation and stage 4 deprivation with total sleep loss: experiment 2. *Psychophysiology* 11(2): 147–159.
Karni A and Sagi D (1991) Where practice makes perfect in texture discrimination: evidence for primary visual cortex plasticity. *Proceedings of the National Academy of Science of the United States of America* 88: 4966–4970.
Karni A and Sagi D (1993) The time course of learning a visual skill. *Nature* 365: 250–252.
Karni A, Tanne D, Rubenstein BS, et al. (1994) Dependence on REM sleep of overnight improvement of a perceptual skill. *Science* 265(5172): 679–682.
Kensinger EA (2004) Remembering emotional experiences: The contribution of valence and arousal. *Rev. Neurosci.* 15(4): 241–251.
Kim JJ and Diamond DM (2002) The stressed hippocampus, synaptic plasticity and lost memories. *Nat. Rev. Neurosci.* 3(6): 453–462.
Kirschbaum C, Wolf OT, May M, et al. (1996) Stress- and treatment-induced elevations of cortisol levels associated with impaired declarative memory in healthy adults. *Life Sci.* 58(17): 1475–1483.
Kleinsmith LJ and Kaplan S (1963) Paired-associate learning as a function of arousal and interpolated interval. *J. Exp. Psychol.* 65: 190–193.
Kleinsmith LJ and Kaplan S (1964) Interaction of arousal and recall interval in nonsense syllable paired-associate learning. *J. Exp. Psychol.* 67: 124–126.
Kleinsmith LJ, Kaplan S, Tarte RD, et al. (1963) The relationship of arousal to short- and longterm verbal recall. *Can. J. Psychol.* 17: 393–397.
Korman M, Raz N, Flash T, et al. (2003) Multiple shifts in the representation of a motor sequence during the acquisition of skilled performance. *Proc. Natl. Acad. Sci. USA* 100(21): 12492–12497.
Kudrimoti HS, Barnes CA, and McNaughton BL (1999) Reactivation of hippocampal cell assemblies: Effects of behavioral state, experience, and EEG dynamics. *J. Neurosci.* 19(10): 4090–4101.
Kuriyama K, Stickgold R, and Walker MP (2004) Sleep-dependent learning and motor-skill complexity. *Learn. Mem.* 11(6): 705–713.
Lee AK and Wilson MA (2002) Memory of sequential experience in the hippocampus during slow wave sleep. *Neuron* 36(6): 1183–1194.
Lewin I and Glaubman H (1975) The effect of REM deprivation: Is it detrimental, beneficial or neutral? *Psychophysiology* 12: 349–353.
Louie K and Wilson MA (2001) Temporally structured replay of awake hippocampal ensemble activity during rapid eye movement sleep. *Neuron* 29(1): 145–156.

Lovatt DJ and Warr PB (1968) Recall after sleep. *Am. J. Psychol.* 81(2): 253–257.

Lupien SJ and Lepage M (2001) Stress, memory, and the hippocampus: can't live with it, can't live without it. *Behav. Brain Res.* 127(1–2): 137–158.

Maquet P (2001) The role of sleep in learning and memory. *Science* 294(5544): 1048–1052.

Maquet P, Laureys S, Peigneux P, et al. (2000) Experience-dependent changes in cerebral activation during human REM sleep. *Nat. Neurosci.* 3(8): 831–836.

Maquet P, Laureys S, Perrin F, et al. (2003) Festina lente: evidence for fast and slow learning processes and a role for sleep in human motor skill learning. *Learn. Mem.* 10(4): 237–239.

Marrosu F, Portas C, Mascia MS, et al. (1995) Microdialysis measurement of cortical and hippocampal acetylcholine release during sleep-wake cycle in freely moving cats. *Brain Res.* 671: 329–332.

McGaugh JL (2000) Memory – a century of consolidation. *Science* 287(5451): 248–251.

McGaugh JL, Introini-Collison IB, Cahill LF, et al. (1993) Neuromodulatory systems and memory storage: Role of the amygdala. *Behav. Brain Res.* 58(1–2): 81–90.

McGaugh JL, Cahill L, and Roozendhaal B (1996) Involvement of the amygdala in memory storage: Interaction with other brain systems. *Proc. Natl. Acad. Sci. USA* 93(24): 13508–13514.

McNaughton BL and Barnes CA, et al. (2003) Off-line reprocessing of recent memory and its role in memory consolidation: A progress report. In: Maquet P, Smith C, and Stickgold R (eds.) *Sleep and Plasticity*, pp. 225–246. London: Oxford University Press.

Mednick SC, Nakayama K, and Cantero JL (2002) The restorative effect of naps on perceptual deterioration. *Nat. Neurosci.* 5: 677–681.

Mednick S, Nakayama K, and Stickgold R (2003) Sleep dependent learning: A nap is as good as a night. *Nat. Neurosci.* 6: 697–698.

Meier-Koll A, Bussmann B, Schmidt C, et al. (1999) Walking through a maze alters the architecture of sleep. *Percept. Mot. Skills* 88: 1141–1159.

Molle M, Marshall L, Gais S, et al. (2002) Grouping of spindle activity during slow oscillations in human non-rapid eye movement sleep. *J. Neurosci.* 22(24): 10941–10947.

Molle M, Marshall L, and Gais S (2004) Learning increases human electroencephalographic coherence during subsequent slow sleep oscillations. *Proc. Natl. Acad. Sci. USA* 10(38): 13963–13968.

Moscovitch M, Nadel L, Winocur G, et al. (2006) The cognitive neuroscience of remote episodic, semantic and spatial memory. *Curr. Opin. Neurobiol.* 16(2): 179–190.

Nadel L and Moscovitch M (1997) Memory consolidation, retrograde amnesia and the hippocampal complex. *Curr. Opin. Neurobiol.* 7(2): 217–227.

Nakanishi H, Sun Y, Nakamura RK, et al. (1997) Positive correlations between cerebral protein synthesis rates and deep sleep in *Macaca mulatta*. *Eur. J. Neurosci.* 9(2): 271–279.

Packard MG and Cahill L (2001) Affective modulation of multiple memory systems. *Curr. Opin. Neurobiol.* 11(6): 752–756.

Pare D, Collins DR, and Pelletier JG (2002) Amygdala oscillations and the consolidation of emotional memories. *Trends Cogn. Sci.* 6: 306–314.

Pavlides C and Winson J (1989) Influences of hippocampal place cell firing in the awake state on the activity of these cells during subsequent sleep episodes. *J. Neurosci.* 9: 2907–2918.

Payne JD and Nadel L (2004) Sleep, dreams, and memory consolidation: The role of the stress hormone cortisol. *Learn. Mem.* 11(6): 671–678.

Payne JD, Nadel L, Allen JJ, et al. (2002) The effects of experimentally induced stress on false recognition. *Memory* 10(1): 1–6.

Payne JD, Nadel L, Britton WB, et al. (2004) The biopsychology of trauma and memory. In: *Memory and Emotion*, pp. 76–128. Oxford University Press.

Payne JD, Jackson ED, Ryan L, et al. (2006) The impact of stress on neutral and emotional aspects of episodic memory. *Memory* 14(1): 1–16.

Pearlman C (1979) REM Sleep and information processing: Evidence from animal studies. *Neurosci. Biobehav. Rev.* 3: 57–68.

Peigneux P, Laureys S, Fuchs S, et al. (2003) Learned material content and acquisition level modulate cerebral reactivation during posttraining rapid-eye-movement sleep. *Neuroimage* 20(1): 125–134.

Peigneux P, Laureys S, Fuchs S, et al. (2004) Are spatial memories strengthened in the human hippocampus during slow wave sleep? *Neuron* 44: 535–545.

Plihal W and Born J (1997) Effects of early and late nocturnal sleep on declarative and procedural memory. *J. Cogn. Neurosci.* 9(4): 534–547.

Plihal W and Born J (1999a) Effects of early and late nocturnal sleep on priming and spatial memory. *Psychophysiology* 36: 571–582.

Plihal W and Born J (1999b) Memory consolidation in human sleep depends on inhibition of glucocorticoid release. *Neuroreport* 10(13): 2741–2747.

Poe GR, Nitz DA, McNaughton BL, et al. (2000) Experience-dependent phase-reversal of hippocampal neuron firing during REM sleep. *Brain Res.* 855(1): 176–180.

Qin YL, McNaughton BL, Skaggs WE, et al. (1997) Memory reprocessing in corticocortical and hippocampocortical neuronal ensembles. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 352(1360): 1525–1533.

Rechtschaffen A and Kales A (1968) *A Manual of Standardized Terminology Techniques and Scoring System for Sleep Stages of Human Subjects*. Los Angeles: University of California Los Angeles, Brain Information Service.

Ribeiro S, Goyal V, Mello CV, et al. (1999) Brain gene expression during REM sleep depends on prior waking experience. *Learn. Mem.* 6: 500–508.

Ribeiro S and Nicolelis MA (2004) Reverberation, storage, and postsynaptic propagation of memories during sleep. *Learn. Mem.* 11(6): 686–696.

Robertson EM, Pascual-Leone A, and Press DZ (2004) Awareness modifies the skill-learning benefits of sleep. *Curr. Biol.* 14(3): 208–212.

Schabus M, Hodlmoser K, Gruber G, et al. (2006) Sleep spindle-related activity in the human EEG and its relation to general cognitive and learning abilities. *Eur. J. Neurosci.* 23(7): 1738–1746.

Schacter DL and Tulving E (1994) *Memory Systems 1994*. Cambridge, MA: MIT Press.

Sejnowski TJ and Destexhe A (2000) Why do we sleep? *Brain Res.* 886(1–2): 208–223.

Siapas AG and Wilson MA (1998) Coordinated interactions between hippocampal ripples and cortical spindles during slow-wave sleep. *Neuron* 21(5): 1123–1128.

Siegel JM (2001) The REM sleep-memory consolidation hypothesis. *Science* 294(5544): 1058–1063.

Sirota A, Csicsvari J, Buhl D, et al. (2003) Communication between neocortex and hippocampus during sleep in rodents. *Proc. Natl. Acad. Sci. USA* 100(4): 2065–2069.

Skaggs WE and McNaughton BL (1996) Replay of neuronal firing sequences in rat hippocampus during sleep following spatial experience. *Science* 271(5257): 1870–1873.

Smith C (1985) Sleep states and learning: a review of the animal literature. *Neurosci. Biobehav. Rev.* 9(2): 157–168.

Smith C (1995) Sleep states and memory processes. *Behav. Brain Res.* 69(1–2): 137–145.
Smith C (2001) Sleep states and memory processes in humans: Procedural versus declarative memory systems. *Sleep Med. Rev.* 5(6): 491–506.
Smith C and Butler S (1982) Paradoxical sleep at selective times following training is necessary for learning. *Physiol. Behav.* 29(3): 469–473.
Smith C and MacNeill C (1994) Impaired motor memory for a pursuit rotor task following stage 2 sleep loss in college students. *J. Sleep Res.* 3: 206–213.
Smith C and Rose GM (1996) Evidence for a paradoxical sleep window for place learning in the Morris water maze. *Physiol. Behav.* 59(1): 93–97.
Smith C and Wong PT (1991) Paradoxical sleep increases predict successful learning in a complex operant task. *Behav. Neurosci.* 105(2): 282–288.
Smith C, Young J, and Young W (1980) Prolonged increases in paradoxical sleep during and after avoidance-task acquisition. *Sleep* 3(1): 67–81.
Smith C, Tenn C, and Annett R (1991) Some biochemical and behavioural aspects of the paradoxical sleep window. *Can. J. Psychol.* 45(2): 115–124.
Smith C, Conway J, and Rose C (1995) Paradoxical sleep deprivation impairs reference memory in the radial maze task. *Sleep Res.* 24: 456.
Squire LR (1992) Declarative and nondeclarative memory: Multiple brain systems supporting learning and memory. *J. Cogn. Neurosci.* 4: 231–243.
Squire LR, Cohen NJ, and Nadel L (1984) The medial temporal region and memory consolidation: A new hypothesis. In: Weingartner H and Parker E (eds.) *Memory Consolidation*, pp. 185–210. Hillsdale, NJ: Erlbaum.
Steriade M (1999) Coherent oscillations and short-term plasticity in corticothalamic networks. *Trends Neurosci.* 22: 337–345.
Steriade M and Timofeev I (2003) Neuronal plasticity in thalamocortical networks during sleep and waking oscillations. *Neuron* 37(4): 563–76.
Stickgold R (2003) Human studies of sleep and off-line memory reprocessing. In: Maquet P, Smith C, and Stickgold R (eds.) *Sleep and Plasticity*, London: Oxford University Press.
Stickgold R (2005) Sleep-dependent memory consolidation. *Nature* 437: 1272–1278.
Stickgold R and Walker MP (2005) Sleep and memory: The ongoing debate. *Sleep* 28: 1225–1227.
Stickgold R, James L, and Hobson A (2000a) Visual discrimination learning requires post-training sleep. *Nat. Neurosci.* 2(12): 1237–1238.
Stickgold R, Whidbee D, Schirmer B, et al. (2000b) Visual discrimination task improvement: A multi-step process occurring during sleep. *J. Cogn. Neurosci.* 12: 246–254.
Stickgold R, Hobson JA, Fosse R, et al. (2001) Sleep, learning and dreams: Off-line memory reprocessing. *Science* 294: 1052–1057.
Takashima A, Petersson KM, Rutters F, et al. (2006) Declarative memory consolidation in humans: A prospective functional magnetic resonance imaging study. *Proc. Natl. Acad. Sci. USA* 103(3): 756–761.
Tucker MA, Hirota Y, Wamsley EJ, et al. (2006) A daytime nap containing solely non-REM sleep enhances declarative but not procedural memory. *Neurobiol. Learn. Mem.* 86(2): 241–247.
Tulving E (1972) Episodic and semantic memory. In: Tulving E and Donaldson W (eds.) *Organization of Memory*, pp. 381–403. New York: Academic Press.
Tweed S, Aubrey JB, Nader R, et al. (1999) Deprivation of REM sleep or stage 2 sleep differentially affects cognitive procedural and motor procedural memory. *Sleep* 22: S241.
Vertes RP and Eastman KE (2000) The case against memory consolidation in REM sleep. *Behav. Brain Sci.* 23: 867–876.
Vertes RP and Siegel JM (2005) Time for the sleep community to take a critical look at the purported role of sleep in memory processing. *Sleep* 28: 1228–1229.
Wagner U, Gais S, and Born J (2001) Emotional memory formation is enhanced across sleep intervals with high amounts of rapid eye movement sleep. *Learn. Mem.* 8: 112–119.
Walker MP and Stickgold R (2004) Sleep-dependent learning and memory consolidation. *Neuron* 44(1): 121–133.
Walker MP and Stickgold R (2006) Sleep, memory, and plasticity. *Annu. Rev. Psychol.* 57: 139–166.
Walker MP, Brakefield T, Hobson JA, and Stickgold R (2002) Practice with sleep makes perfect: Sleep dependent motor skill learning. *Neuron* 35(1): 205–211.
Walker MP, Brakefield T, Seidman J, et al. (2003) Sleep and the time course of motor skill learning. *Learn. Mem.* 10: 275–284.
Wilson MA and McNaughton BL (1994) Reactivation of hippocampal ensemble memories during sleep. *Science* 265: 676–679.
Wixted JT (2004) The psychology and neuroscience of forgetting. *Annu. Rev. Psychol.* 55: 235–269.
Yaroush R, Sullivan MJ, and Ekstrand BR (1971) Effect of sleep on memory. II: Differential effect of first and second half of the night. *J. Exp. Psychol.* 88: 361–366.

# 2.36 Infant Memory

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## 2.36.1 Introduction

Infant memory is a burgeoning topic, difficult to comprehend and difficult to summarize, but one thing is clear: Infants from their inception have robust capacities to learn and remember. In the development of these capacities are hidden the secrets of adult learning and memory.

The infancy period extends from birth through 2 years of age. Over this period, the infant is dramatically transformed from a helpless, altricial organism who sleeps 99% of the time and depends on its parents for nourishment and protection into an active, highly social being who sleeps largely at night, locomotes independently, and exhibits unflagging curiosity (**Figure 1**). A central problem in cognition is understanding how the superior memory of adults evolves from the memory ability of infants. This is the question of how we came to be as we are. In this chapter, we review research that has shed some light on the solution to this problem. We conclude that memory processing in infants and adults is fundamentally the same.

### 2.36.1.1 Paradox of Infant Memory

Developmental scientists have long assumed that the effects of infants' early experiences gradually accrue and lay the foundation for their later cognitive development (Watson, 1930; Stevenson et al., 1967). Paradoxically, although this assumption requires

**Figure 1** From left to right, infants are 2, 3, 6, 9, 12, 15, and 18 months of age. Note the dramatic physical and behavioral differences between the youngest and oldest infant.

that infants maintain a relatively enduring record of their early experiences, most also believe that infants lack the ability to do so. They think that the infant brain is too immature to encode or retrieve memories of specific events (Nelson, 1995; Liston and Kagan, 2002; Bauer et al., 2007), that infants younger than 18 months cannot form mental representations (Piaget, 1962; Anisfeld, 2005), or that the ability "to retain a memory over a long period of time [is] not possible" before the child can converse about it with others (Nelson, 1990: p. 307).

Researchers from different laboratories using different procedures, however, have amassed compelling evidence that preverbal infants can retain memories of their experiences for periods ranging from days and weeks to months and years (for reviews, see Rovee-Collier et al., 2001; Hayne, 2004, 2007).

### 2.36.1.2 Associative Memory and Retentive Memory

Associations play a central role in accounts of learning and memory phenomena. The formation of an association between two events is determined by their temporal contiguity. If an association is formed between two events that are separated by a delay, then the individual is said to have exhibited associative memory over the delay (Revusky, 1971). The upper limit of associative memory is the maximum interval between the conditional and unconditional stimuli that leads to classical conditioning and the maximum delay between a response and reinforcement that leads to operant conditioning.

Relative to associative memory, retentive memory is long lasting (Revusky, 1971). It is implicated when an individual exhibits the effect of prior training over an interval between training and testing. Watson (1984) referred to these forms of memory as memory in learning and memory of learning, respectively. This chapter focuses primarily on retentive (long-term) memory.

### 2.36.1.3 Historical Perspectives

The systematic study of infant long-term memory can be traced to Fagan's (1970) report of visual recognition memory with 5-month-olds and Rovee and Fagen's (1976) report of delayed recognition with operantly trained 3-month-olds. Earlier reports, often anecdotal, were of single subjects who were observed over long periods. In his autobiography, for example, John Stuart Mill said that his father, James Mill, taught him formal Greek at the age of 3, which he used throughout his life (Mill, 1909). In a single-subject study of the long-term maintenance of early memory, Burtt (1932, 1937, 1941) read the same Greek passages to his infant son once daily between 15 and 36 months of age, introducing a different set of passages every 3 months. When the child was 8.5, 14, and 18 years old, Burtt measured savings during relearning of the passages. Early exposure to the passages produced the largest savings at 8.5 years (a 5-year retention interval), when the child required 30% fewer repetitions to relearn old passages than to learn new ones. Savings were smaller (8%) at 14 years and negligible at 18 years.

The classic study of Little Albert also provided evidence of long-term memory (Watson and Rayner, 1920). Here, the authors asked whether a conditioned emotional reaction (CER) could be established in an 11-month-old infant. Albert initially exhibited no aversive reactions to various novel stimuli, including a white rat. A loud noise was then sounded directly behind Albert's head on two occasions that he reached for the rat. The noise produced crying and hand withdrawal, which transferred to the rat. One week later, Albert still withdrew his hand when presented with the rat; in this session, he also received five more rat-noise pairings. Five days later, Albert generalized the CER to test objects that shared perceptually similar properties with the rat (a rabbit, dog, fur coat, Santa Claus mask, cotton) but did not generalize to perceptually different objects (wooden blocks). After an additional 10 days, Albert's CER to the rat had become muted and was freshened by another rat-noise presentation. The rabbit and dog were also explicitly paired with the noise during this session. One month later, Albert still exhibited strong CERs to the rat, dog, mask, and fur coat.

In another early study, Jones (1930) exposed a 7-month-old to repeated pairings of a tapping sound (the conditional stimulus, or CS) and an electrotactual stimulus (the unconditional stimulus, or US) for 5 days. The CR (conditional response), a galvanic skin reflex, was established in session 1. Despite receiving no additional conditioning trials in the interim, the infant still exhibited the CR 6 weeks later, and the CR had not completely disappeared after 7 weeks.

## 2.36.2 Methods of Study

The major impediment to research on the ontogeny of infant memory has always been methodological: The tasks commonly used with older infants are usually inappropriate for use with younger ones. This problem is hardly surprising when one considers the rapid physical and behavioral changes that infants undergo over the first 18 months of life (**Figure 1**). As a result, researchers used a hodgepodge of tasks with stimuli, task parameters, and task demands that varied nonsystematically with infants of different ages, making cross-age comparisons dubious at best. In addition, the use of verbal prompts biased results in favor of older, linguistically more competent infants. Within the last decade, new operant and deferred imitation tasks were developed to overcome this obstacle.

Most of what is known about infant memory has come from research with visual recognition memory, operant conditioning, and deferred imitation tasks. In visual recognition memory tasks, retention is measured indirectly, inferred from general reactions such as looking/orienting, electrophysiological and psychophysiological responses, facial expressions, and so forth. In these instances, the meaning of a response is a matter of interpretation (Lewis, 1967; Haith, 1972). In classical conditioning, operant conditioning, and deferred imitation tasks, retention is measured directly in the performance of a previously learned behavior.

### 2.36.2.1 Visual Recognition Memory

Visual recognition memory is studied using the visual paired-comparison (VPC) task (Fantz, 1956, 1964; Fagan, 1970) and the habituation task (Berlyne, 1958; Cohen and Gelber, 1975). Both exploit infants' propensity to look longer at novel than at familiar stimuli. The underlying assumption is that infants who exhibit a novelty preference must remember what they saw before. Recognition of a preexposed stimulus, therefore, is inferred from the relative extent to which infants look at a novel one.

In the VPC task, infants view two identical stimuli presented side by side (or occasionally only one) for a fixed duration. During the retention test, a novel stimulus replaces one of them (**Figure 2**).

**Figure 2** The visual paired-comparison (VPC) test with a 6-month-old infant. Immediately before the test, the infant was shown two identical pictures of the woman's face. During the test, the infant is shown the previously exposed picture (the woman's face) and a novel one (the man's face). Proportionally longer looking at the novel picture is taken as evidence that the infant recognized the preexposed one.

Recognition of the original stimulus is inferred if the percent of total time spent looking at the novel stimulus significantly exceeds chance (50%). The upper limit of retention is the longest test delay at which infants fixate the novel stimulus more.

In the habituation task, infants are repeatedly exposed to one stimulus until looking time decreases by a specified amount, at which point they are successively tested with a novel stimulus and the original one. Increased looking at the novel stimulus indicates recognition of the original one. As the interval between the final habituation trial and testing increases, infants look increasingly longer at the original stimulus. The delay after which they fixate it for as long as they had on Trial 1 indicates forgetting.

Visual recognition memory tasks that are administered in one session provide a measure of short-term memory. In this situation, the upper limit of retention approximates 5–15 s at 3–4 months, 1 min at 6 months, and 10 min at 9–12 months (Diamond, 1990; Rose et al., 2004). Long-term memory is implicated when multiple sessions are administered. Using the VPC task over multiple daily sessions, Fagan (1973) found that 4–5-month-olds looked longer at a novel black-and-white pattern after 48 h and at a novel facial photograph after 2 weeks. Face recognition, however, may be special. Following habituation to faces, infants exhibit significant recognition after 2 min at 3 days of age (Pascalis and de Schonen, 1994) and after 24 h at 3 months of age (Pascalis et al., 1998).

### 2.36.2.2 Delayed Nonmatching-to-Sample

The delayed nonmatching-to-sample (DNMS) task is analogous to the VPC task but requires substantial motor coordination. Initially a reward (cereal, toy) is hidden in a well under a sample object, and infants retrieve the reward by displacing the sample. After a delay, the sample and a novel object are presented simultaneously, but the reward is under the novel one. To retrieve the reward, infants must recognize the sample object and displace the novel one. The upper limit of associative memory is the maximum delay after the sample trial when infants retrieve the reward. Infants younger than 15–21 months fail standard DNMS tasks after 5–10 s (Overman, 1990; Diamond et al., 1994). When the reward is the opportunity to play with the novel object, however, even 6-month-olds succeed after 10 min (Diamond, 1995).

### 2.36.2.3 Classical Conditioning

In classical conditioning, infants acquire an association between two stimuli, a CS and a US, that usually occur in succession. They must remember the CS until the US occurs (associative memory). The upper limit of associative memory is the maximum interval between the CS and US (ISI, interstimulus interval) that promotes learning.

In eyeblink conditioning, the optimal ISI is three to four times longer for infants than adults (Kimble, 1947). Using a delay conditioning procedure, Little (1970) presented 2-month-olds with a tone (CS) and airpuff (US) at ISIs of 500, 1000, 1500, or 2000 ms. Only the two longest ISIs promoted conditioning. Little et al. (1984) used 500-ms and 1500-ms ISIs with 10-, 20-, and 30-day-olds. At all ages, infants exhibited associative memory after the 1500-ms ISI only, and only 20- and 30-day-olds exhibited significant retention of the association (retentive memory) on a savings measure 10 days later (**Figure 3**). The optimal ISI decreases to 650 ms at 4–5 months of age (Ivkovich et al., 1999) and 500 ms in adults (Kimble, 1947). This decrease parallels an increase in synaptic efficacy (Kandel and Hawkins, 1992) and may reflect changes in infants' ability to perceive the CS and US as distinct events.

### 2.36.2.4 Operant Conditioning

In operant conditioning, infants acquire an association between a response and reinforcement. They must remember the response until reinforcement occurs (associative memory). The upper limit of associative memory is the maximum response-reinforcement interval that promotes learning. The upper limit is 0 s (immediate reinforcement) at 3 months (Ramey and Ourth, 1971), 1–2 s from 6 to 8 months (Millar, 1990), and 9 s from 9 to 16 months (Brody, 1981).

The most extensive analysis of infants' long-term memory (retentive memory) has come from operant research with the mobile conjugate reinforcement task (Rovee and Rovee, 1969) and its upward extension, the train task (Hartshorn and Rovee-Collier, 1997; for review, see Rovee-Collier et al., 2001). The logic behind using these tasks is straightforward: Because infants lack a verbal response to say what they recognize, they are taught a motoric one (a foot kick or lever press) that they can use instead. When tested with a display that is the same as or different from the training one, infants 'say' whether or not

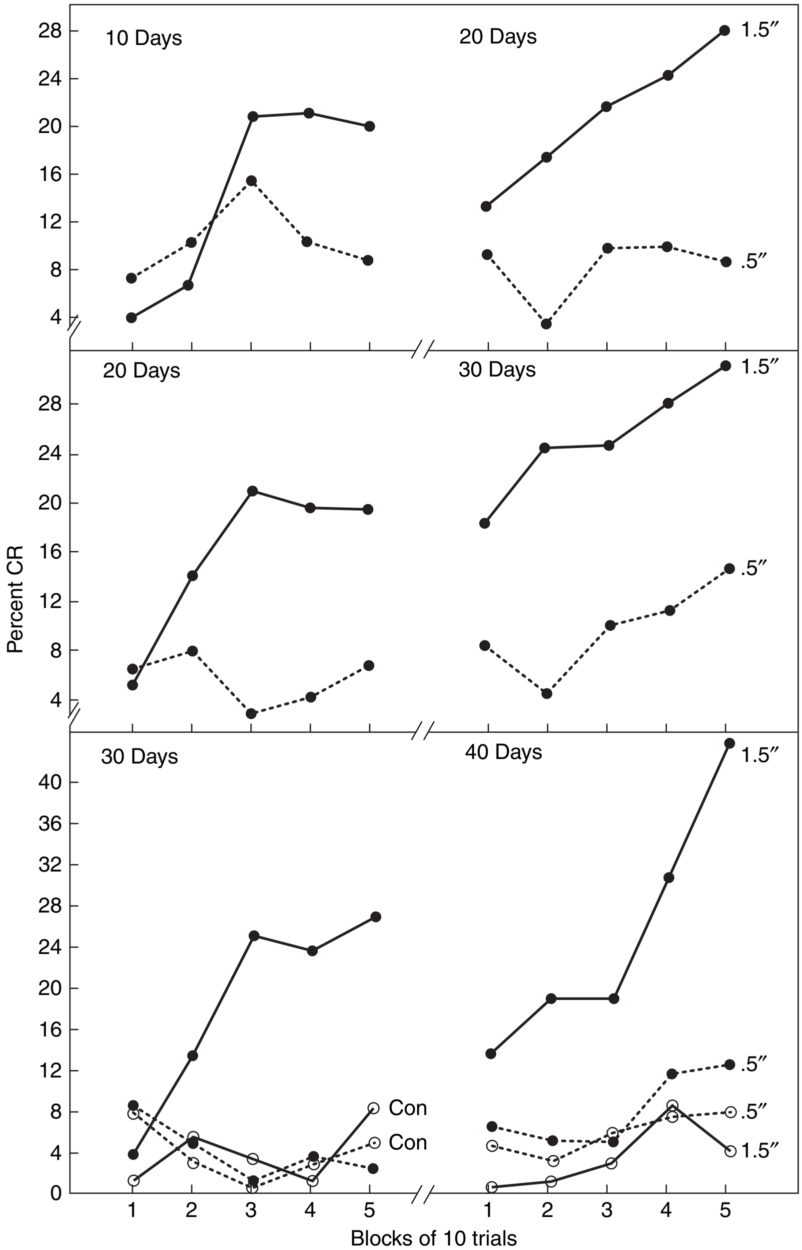


**Figure 3** Percentage of responses on conditional stimulus–unconditional stimulus (CS–US) trials by infants who were classically conditioned at 10, 20, or 30 days of age (left panels) to blink their eyes to a tone (CS) that was paired with an air puff (US) and were retrained in a second session 10 days later (right panels). The CS and US were separated by either a 1500-ms or 500-ms interstimulus interval (ISI). Reprinted with permission from Little AH, Lipsitt LP, and Rovee-Collier C (1984) Classical conditioning and retention of the infant's eyelid response: Effects of age and interstimulus interval. *J. Exp. Child Psychol.* 37: 512–524. Copyright © Academic Press, Inc.

they recognize it by whether or not they produce the learned response.

In all studies, infants are trained in their homes for two sessions 24 h apart. At 2–6 months, the mobile task is used (**Figure (4a)–(4c)**). During the 9-min acquisition periods (6 min at 6 months) in each session, kicks are conjugately reinforced by mobile movement via a ribbon that is strung from the infant's ankle to the same suspension hook as an overhead crib mobile (**Figure 4(b)**). During 3-min nonreinforcement periods (2 min at 6 months) at the beginning and end of each session, the ankle ribbon is connected


**Figure 4** The experimental arrangement used with 2- to 6-month-olds in the operant mobile task, shown here with a 3-month-old. From top to bottom, (a) Baseline: The ankle ribbon and mobile are connected to different hooks, and kicks do not move the mobile; (b) Acquisition: Kicks conjugately move the mobile via an ankle ribbon connected to the mobile hook; (c) Immediate retention test, long-term retention test: The ankle ribbon and mobile are again connected to different hooks. Infants who recognize the mobile kick to move it during the test, even though they cannot.

to an empty suspension hook, and kicks cannot move the mobile (Figures 4(a), 4(c)). The baseline kick rate (operant level) is measured during the first nonreinforcement period in session 1; the response rate that indicates the final level of learning is measured during the last nonreinforcement period in session 2 (the immediate retention test). To proceed beyond the training phase, each infant must satisfy a learning criterion (responding 1.5 times above the baseline rate).

The long-term retention test occurs days to weeks later and is another 3-min (2 min at 6 months) nonreinforcement period when the response rate is measured again. Because individual operant levels vary widely, an infant's responding during the long-term retention test is expressed as a ratio of the same infant's responding during the baseline phase (the baseline ratio) and the immediate retention test (the retention ratio). A group baseline ratio that significantly exceeds 1.00 indicates retention; if the accompanying retention ratio is significantly below 1.00 (i.e., significant forgetting), however, then the group's retention is partial. Because long-term retention is assessed during a nonreinforcement period, savings (faster relearning) are not measured.

Because the mobile task cannot be used with infants older than 6–7 months, the train task was developed as an upward extension of the mobile task for infants between 6 and 24 months (Figure 5). Instead of moving a mobile by kicking, infants move a miniature train around a circular track by lever pressing. During reinforcement periods, each discrete lever press moves the train for 1 s (2 s at 6 months); during nonreinforcement periods, the lever is deactivated. At 6 months, all retention measures in the two tasks are identical, including the rate of forgetting before and after

**Figure 5** The experimental arrangement used with 6- to 24-month-olds in the operant train task, shown here with a 6-month-old. Each lever press moves the toy train for 2 s (1 s at older ages) during acquisition; during baseline and all retention tests, the lever is deactivated, and presses do not move the train.

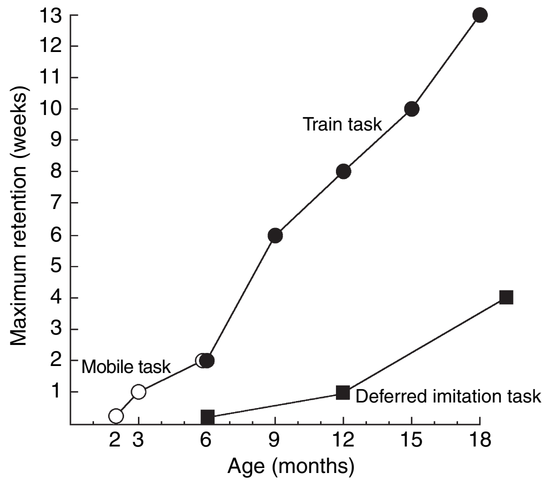


**Figure 6** Standardized reference functions for the maximum duration of retention (in weeks) of infants who were trained and tested in standardized procedures with age-calibrated parameters. The experimental paradigms were the operant mobile and train tasks and the deferred imitation (puppet) task. Differences in the slopes of the two functions are solely the result of the use of different parameters. From Hartshorn K, Rovee-Collier C, Gerhardstein P, et al. (1998b) The ontogeny of long-term memory over the first year and a half of life. *Dev. Psychobiol.* 32: 69–89.

priming (Hildreth and Rovee-Collier, 2002), the latency of responding to a memory prime (Hildreth and Rovee-Collier, 1999), responding to cue or context changes before and after priming (DeFrancisco, in press; Hartshorn et al., 1998a), the minimum duration of an effective prime (Sweeney and Rovee-Collier, 2001), and the faster forgetting rate after a minimum-duration prime (Hsu et al., 2005). This equivalence permitted the mobile and train tasks to be used in combination to study memory development systematically over the entire infancy period.

**Figure 6** shows that the maximum duration of retention increases linearly with age over the first year and a half of life. The overlapping points at 6 months show that infants' memory performance is not task specific. These data provide no hint that memory changes qualitatively at the end of the first year of life, when a late-maturing memory system is thought to emerge (Schacter and Moscovitch, 1984), or during the second year of life, when spoken language first appears (Best, 1984).

## 2.36.2.5 Deferred Imitation

In deferred imitation tasks, infants reproduce one or more target actions after a delay. Both Piaget (1962) and Meltzoff (1995) argued that true imitation prohibited performing the modeled behavior before the delayed test, so that imitation would reflect only the memory of what was seen and not what was done. Piaget claimed that infants younger than 18 months could not form mental representations and hence were incapable of true imitation. His claim was refuted by evidence that, with no opportunity to practice, 14-month-olds imitated a novel action (pulling apart a toy) 24 h later (Meltzoff, 1985), and 9-month-olds imitated three unique, single-step actions 24 h later (Meltzoff, 1988).

Barr et al. (1996) developed a task that permitted the systematic study of deferred imitation from 6 to 24 months of age. Here, infants watch an experimenter model three actions on an acrylic hand puppet wearing a same-color mitten (**Figure 7**). Modeling one sequence of actions (remove the mitten, shake it thereby ringing a jingle bell pinned inside during modeling, and replace the mitten) takes 10 s. Three repetitions (30 s) yield immediate imitation at 6 months and 24-h deferred imitation at 9–24 months; six repetitions (60 s) yield 24-h retention at 6 months. An infant's imitation score is the total number of actions copied within 90–120 s of touching the puppet. Between 6 and 24 months of age, the base rate of spontaneously producing the target actions is low (0.13–0.17). Older infants have higher imitation scores and remember progressively longer. The pattern of long-term retention in deferred imitation tasks is the same as in operant tasks except that the slope is flatter and the asymptote is lower (**Figure 6**).

**Figure 7** The experimental arrangement used with 6- to 24-month-old infants in deferred imitation studies. Shown here is the experimenter modeling the three target actions to a 6-month-old.

These differences reflect task differences in training (30–60 s in one modeling session vs. 11–30 min over two conditioning sessions 24 h apart).

Development of the puppet imitation task spawned numerous studies with 6-month-olds (for review, see Hayne, 2004, 2007). Because infants younger than 6 months are motorically limited, whether they could exhibit deferred imitation was unknown until recently, when this problem was overcome by periodically reactivating the memory of the demonstration until they could finally perform the actions (Campanella and Rovee-Collier, 2005). Three-month-olds watched three target actions modeled six times (a total of 60 s) on a puppet. Over the next 3 months, infants received a total of six 30- to 60-s exposures to the stationary puppet. At 6 months of age, they successfully imitated the actions. These infants had not seen the target actions since they were modeled 3 months earlier and obviously had not imitated them immediately. A yoked reactivation control group received the same reminders but did not see the demonstration. It responded at the base rate during the long-term test. These results clearly indicate that the memory system of very young infants is sufficiently mature to support deferred imitation.

#### 2.36.2.6 Elicited Imitation

Elicited imitation is a variant of deferred imitation in which infants imitate immediately (and sometimes during the retention interval) and experimenters provide verbal prompts. Both factors significantly affect infants' deferred imitation: Immediate practice facilitates generalization and priming (Hayne et al., 2003; Learmonth et al., 2004), and verbal cues facilitate imitation after long delays (Hayne, 2004; Hayne and Herbert, 2004).

Elicited imitation tasks have been used with infants between 9 and 32 months to assess their ability to imitate multistep actions (for review, see Bauer, 2004; Bauer et al., 2007). Researchers have consistently reported that the structure of an event influences imitation (Bauer et al., 1995). Imitation of actions that must be performed in a specific order (e.g., putting a toy bear in bed before covering it with a blanket) is superior to imitation of actions that can be performed in any order (e.g., removing the bear's coat and hat). The same result has been found with older children (Fivush et al., 1992) and adults (Ratner et al., 1986).

#### 2.36.2.7 The Ruler Matters

Retention depends on how it is measured. Adults' retention of serial lists, for example, is better when measured by recognition than by recall or relearning (Postman and Rau, 1957, cited in Crowder, 1976). For infants, visual recognition measures of retention range from 5 s at 3 months to 10 min at 12 months (for review, see Rose et al., 2004), but operant measures fix retention from 5 days to 8 weeks over the same period (Hartshorn et al., 1998b). Even under the same conditions of testing, novelty preference and operant measures yield different estimates of retention. Wilk et al. (2001) trained 3- and 6-month-olds in the mobile task and gave them a paired-comparison test with the original mobile and a novel one 1–21 days later. In multiple experiments, infants consistently exhibited long-term retention on the operant measure but not on the VPC measure, looking longer at the training mobile. They concluded that infants look at what is predictive.

Using a split within-subjects design, Gross et al. (2002) exposed 6-month-olds to a picture in a visual recognition memory task and to either a hand puppet on which actions had been modeled or a mobile that they had moved by kicking. Immediately after modeling or operant training, the infants administered a VPC test with the original stimulus and a novel one, followed by a performance test with the original puppet or mobile. On VPC tests, infants looked longer at the novel picture but not at the novel puppet or mobile, indicating a failure to recognize them. On performance tests, however, the same infants imitated the modeled actions on the original puppet and kicked significantly above baseline to the mobile. Again, infants remembered at the predictive stimulus.

### 2.36.3 Reminders

Reinstatement and reactivation reminders have been used with infants of all ages to maintain, extend, or recover memories of earlier experiences. During reinstatement, infants are returned to the original training conditions during the retention interval and given a small amount of partial practice or repetition of the original event (Campbell and Jaynes, 1966). A reactivation procedure entails exposing infants to an isolated component or fragment of the original event at the end of the retention interval, after the memory was forgotten but before the long-term test

(Spear and Parsons, 1976). For both reminders, the essential control groups are the same: a forgetting control group that receives training but no reminder(s) and a reactivation or reinstatement control group that receives reminder(s) but no training.

Most scientists regard reinstatement and reactivation reminders as equivalent (e.g., Hudson and Sheffield, 1998; Mandler, 1998). Howe et al. (1993) wrote that the distinction between them "is artificial in that both . . . have similar (if not the same) memory-preserving effects" (Howe et al., 1993: p. 855), and Richardson et al. (1993) wrote, "there are some minor procedural differences between reactivation and reinstatement. . ., [but] the underlying process is the same in both cases" (Richardson et al., 1993: p. 2). Operant research with infants, however, has revealed that the two reminders differ functionally as well as procedurally. At 3 and 6 months of age, for example, retention is two times longer after reinstatement than reactivation when both are given midway through the forgetting function (Adler et al., 2000; Galluccio and Rovee-Collier, 2006) and ten times longer when both are given after the memory is forgotten (Hildreth et al., 2003). Also, three reinstatements protract retention longer than three reactivations (Hayne, 1990; Galluccio and Rovee-Collier, 1999).

What accounts for the superiority of reinstatement is unclear. Reinstatement is a partial learning trial, but it protracts retention longer than an equivalent amount of overtraining (Adler et al., 2000). Reactivation, on the other hand, is a retrieval trial that has been likened to rehearsal in nonverbal animals (Wagner, 1976). For now, this question remains unanswered.

### 2.36.3.1 Reactivation

Reactivation procedures used with infants and priming procedures used with amnesic adults are the same. Reactivation, like priming in amnesics, is an automatic, perceptual identification process that re-activates a preexisting memory representation and brings it to mind at a time when neither the prime nor the target item can be recognized (Schacter, 1990, 1992; Rovee-Collier, 1997). Because the time required for 3-month-olds to exhibit renewed retention after reactivation is so long (24 h), whereas amnesics respond to a prime (e.g., a word fragment) instantaneously, skeptics initially doubted that that reactivation and priming were the same. Hildreth and Rovee-Collier (1999), however, found that the latency of responding to a memory prime decreased linearly over the first year of life, from 24 h at 3 months to 1 h at 6 months and 1 min at 9 months. By 12 months, infants responded to the prime instantaneously, just like adults. These results confirmed that reactivation in infants and priming in adults are the same.

For both infants and adults, effective primes are hyperspecific to the original event, an extreme instance of encoding specificity (Tulving and Thomson, 1973). Effective primes for infants between 2 and 24 months include the reinforcer (Hsu and Rovee-Collier, 2006), the distinctive training context (Rovee-Collier et al., 1985; Hayne and Findlay, 1995), the demonstration hand puppet (Hayne et al., 2003; Campanella and Rovee-Collier, 2005), the occlusion event (Shuwairi and Johnson, 2006), a pre-exposed photograph (Cornell, 1979), the modeled actions (Barr et al., 2002), a subset of structured activities (Sheffield and Hudson, 1994), photographs of partially completed activities (Deocampo and Hudson, 2003), and a video of another child performing the activities (Sheffield and Hudson, 2006).

During reactivation in the mobile task, infants are in a sling-seat (to minimize activity) under the mobile (**Figure 8**). Instead of being connected to the ankle, the ribbon is used by the experimenter to move the mobile at the same rate that each infant had kicked to move it at the end of acquisition, thus ensuring that the prime is phenomenologically identical to what infants saw before. In the train task, the response lever is deactivated, and the computer is programmed to move the train accordingly.

**Figure 8** The experimental arrangement during reactivation (priming), shown here with a 3-month-old. The ribbon was not connected to the infant's ankle but was held by the experimenter, who pulled it to move the mobile at the same rate that the infant had moved it by kicking during the last few training minutes. The infant seat minimized spontaneous kicking.

In the first reactivation study with infants, 3-month-olds were trained in the mobile task, allowed to forget it, and then were primed either 13 or 27 days later. Independent groups received a standard retention test 24 h later and after longer delays until they reforgot the task (Rovee-Collier et al., 1980). (Because kicking is also a general excitement behavior, priming occurred 24 h before the test so that any arousal it might induce would dissipate.) Priming restored responding to its original level, and infants forgot the reactivated memory at the same rate as the original one (**Figure 9**). Both results have since been obtained throughout the infancy period. The duration of retention increases linearly with age between 2 and 18 months (**Figure 10**, squares), and a reactivation reminder doubles it (**Figure 10**, diamonds; Hildreth and Rovee-Collier, 2002; Hsu et al., 2005). Thus, although reactivation does not protract retention as long as reinstatement, its consequences are nontrivial.

There is an upper limit to how long after training the memory can be primed successfully. Because retention is a monotonically increasing function of age, the absolute upper limit of reactivation increases linearly over the first year as well (**Figure 10**, triangles). The original memory can be reactivated after delays ranging from 1 month (3-month-olds) to 8 months (12-month-olds). When the upper limit of reactivation is expressed as a ratio of the maximum duration that infants typically remember at a given age, the relative upper limit is constant over ages, four times longer than the duration of original retention at a given age (Hildreth and Hill, 2003). The absolute upper limit of reactivation did not continue to increase beyond its peak at 12 months because infants trained at 15–18 months outgrew the train task by the time of testing. As a result, they could not be tested after relative delays longer than 1.5–2 times the duration of original retention (Hsu and Rovee-Collier, 2006). (The long-term retention test is an increasingly conservative test of retention as infants approach 2 years of age. Older infants often stop lever pressing when the train does not move and remark that it is broken or needs batteries.)

At 3 months of age, multiple reactivations flatten the forgetting function (Hayne, 1990), extend retention from 4 weeks with one reminder (Rovee-Collier et al., 1980) to at least 6 weeks with two reminders (Hayne, 1990), speed the memory recovery from 24 h with one reminder (Fagen and Rovee-Collier, 1983) to 1 h with two reminders (Hayne et al., 2000b), reduce the minimum duration exposure to a prime 1 week after forgetting from 2 min with one reminder (Joh et al., 2002) to 1 min with two reminders (Bearce and Rovee-Collier, 2006), and reduce the accessibility of

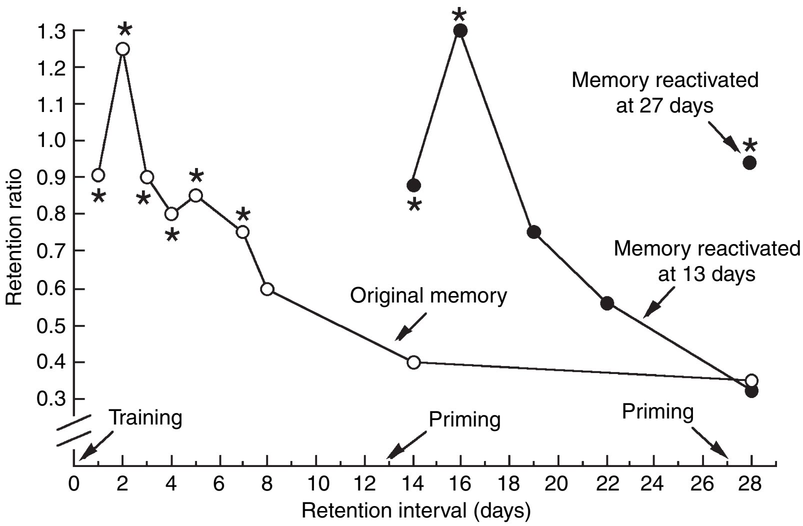


**Figure 9** The forgetting and reforgetting functions of the original memory and the reactivated memory, respectively, as a function of the number of days after training or priming when retention was tested. Priming occurred either 13 or 27 days after training was over. Irrespective of priming delay, retention was renewed at the same level that it was 24 h after training. An asterisk indicates significant retention. Reprinted with permission from Rovee-Collier C, Sullivan MW, Enright MK, Lucas D, and Fagen JW (1980) Reactivation of infant memory. *Science* 208: 1159–1161. Copyright © 1980 by the American Association for the Advancement of Science.

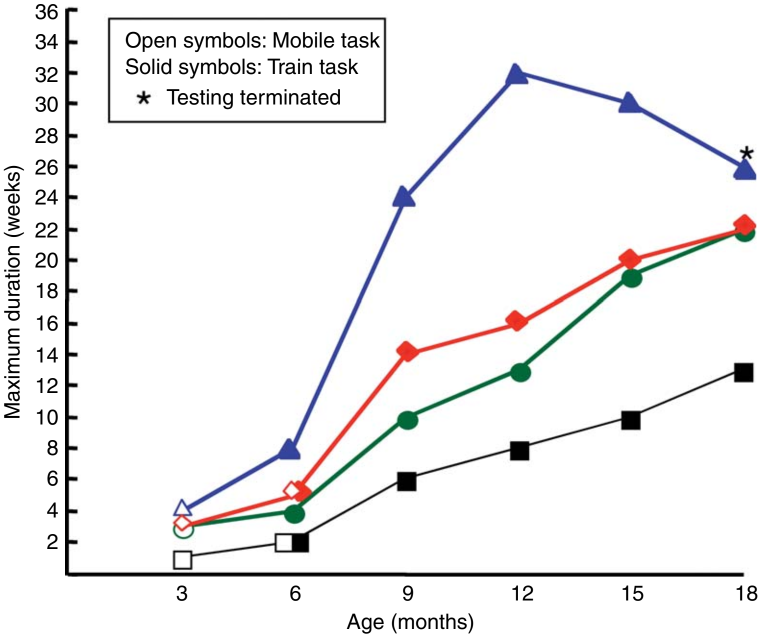


**Figure 10** The absolute length of time that the memory (mobile task: open symbols; train task: solid symbols) was accessible between 3 and 18 months of age. The squares represent the duration of retention of the newly acquired memory of the operant task. Infants had a 1- or 2-week delay between forgetting of the task and reactivation with either the minimum-duration or full-length prime. In the functions, diamonds represent retention of the reactivated memory following a full-length prime, circles represent retention of the reactivated memory following a minimum-duration prime, and triangles represent retention of the memory that was reactivated near or at the upper limit of reactivation. An asterisk indicates that the experiment was terminated because older infants outgrew the task. Reprinted with permission from Hsu VC and Rovee-Collier C (2006) Memory reactivation in the second year of life. *Infant Behav. Dev.* 28: 1–17. Copyright © 2006 by Elsevier Inc.

memory attributes representing contextual details (Hitchcock and Rovee-Collier, 1996).

Finally, Shuwairi and Johnson (2006) used an innovative application of reactivation as a precue to probe whether explicit training with an occlusion event had an enduring effect on anticipatory eye movements. For either one or four training trials, 4-month-olds watched a ball move back and forth on a constant trajectory on a video monitor (**Figure 11(a)–(d)**). On test trials, its path was partially occluded. Immediately after training, the proportion of total eye movements that anticipated the ball's reemergence from behind the occluder significantly exceeded that of a baseline control group after four 30-s trials but not after one 30-s trial (**Figure 12**). Thirty minutes after training, when the memory was forgotten, infants received a single 30-s trial (a precue) immediately before the retention test. (Recall that one 30-s trial produced no learning.) The prime reactivated the training memory and restored anticipations to the previous level (**Figure 12**). This result indicates that early and relatively brief exposures to occlusion events produce stable and relatively enduring object representations that can be maintained and potentially strengthened by repeated reminders.

### 2.36.3.2 Reinstatement

During reinstatement in the mobile and train tasks, the ankle ribbon is connected to the mobile hook and the response lever is active, so that kicks and lever presses are reinforced. In both tasks, reinstatement is timed from the first response and lasts 3 min at 2–3 months and 2 min at 6–18 months. This regimen is insufficient to produce 24-h retention of new learning during reminding.

Hartshorn (2003) tested Campbell and Jaynes's (1966) original hypothesis that reinstatement is the mechanism by which early memories are maintained over significant periods of behavioral development. Recall that 6-month-olds typically remember the train task for 2 weeks. In three progressive replications, 6-month-olds learned the train task, received a 2-min reinstatement at 7, 8, 9, and 12 months of age, and were tested at 18 months of age. Prior to

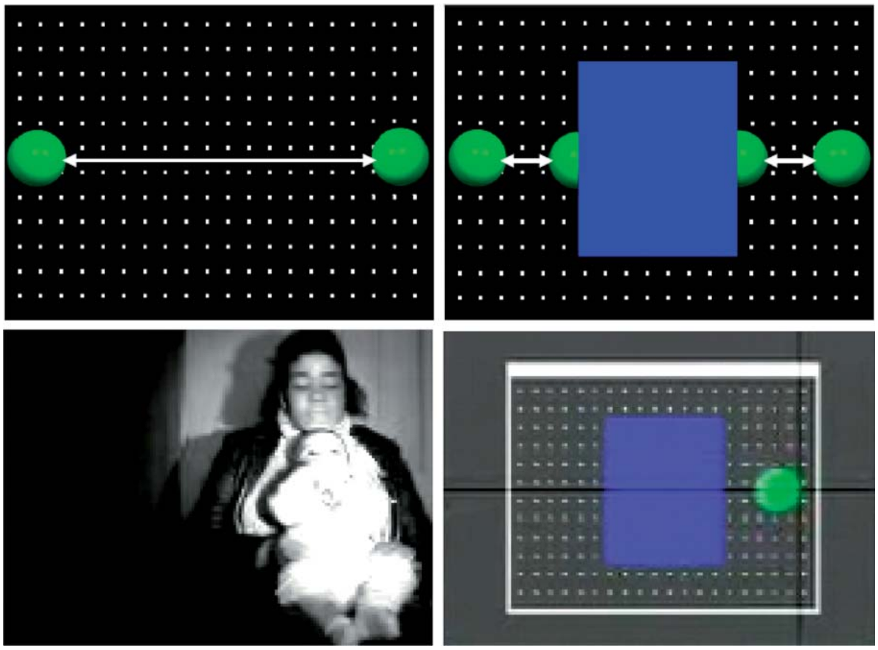

**Figure 11** The experimental arrangement and stimuli used to study anticipatory eye movements in the eye-tracking paradigm. (a) Unoccluded (training) trial: The ball moved horizontally back and forth along an unoccluded trajectory. (b) Occluded (test) trial: The ball moved horizontally back and forth along an occluded trajectory. The ball moved behind a blue box and reemerged on the opposite side. (c) The experimental arrangement with a 4-month-old infant. (d) The corneal reflection eye tracker recorded the infant's visual fixation (the black cross to the right of the ball) as the ball emerged from behind the occluded object. Figure courtesy of Sarah M. Shuwairi and Scott P. Johnson.

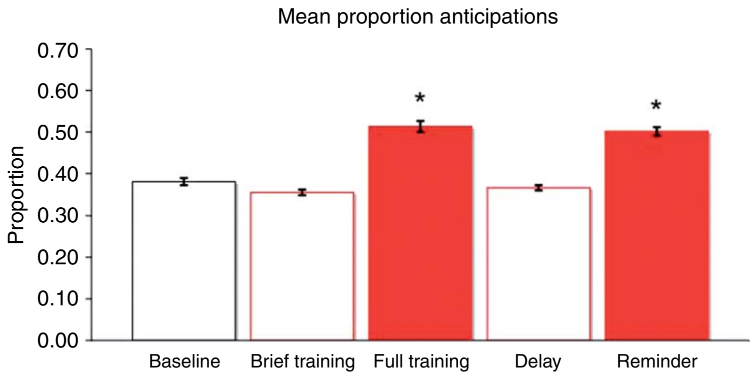


**Figure 12** Mean proportion of anticipatory eye movements of independent groups of 4-month-old infants. The experimental groups received either a brief (Brief training) or full (Full training, Delay, Reminder) training regimen and were tested either immediately after training (Brief training, Full training) or after a 30-min delay (Delay, Reminder). The reminder condition received a brief training trial immediately prior to testing. An asterisk indicates significant anticipations relative to the baseline control group. Vertical bars indicate + 1 SE. Figures courtesy of Sarah M. Shuwairi and Scott P. Johnson.

reminding at 9 and 12 months, infants received a 2-min retention test as a memory probe. All infants not only remembered the task then but also remembered it during the 18-month test, 1 year after training. In each replication, yoked reinstatement control groups that received the same reinstatements but were not originally trained exhibited no retention after any delay. Immediately after the 18-month test, Hartshorn gave infants another reinstatement and retested them 6 months later, at 24 months of age. The infants also exhibited significant retention during the 24-month test, 1.5 years after they were originally trained, despite receiving only one reinstatement in the preceding year.

In a concurrent study, Rovee-Collier et al. (1999) trained 2-month-olds in the mobile task and then administered either a reinstatement or a reactivation reminder every 3 weeks. Before each reminder, they presented a preliminary retention test as a memory probe to assess whether an infant remembered the task. Infants who did remember received a reinstatement, while those who did not received a reactivation reminder. Even though 2-month-olds typically remember the mobile task for only 1–2 days, they remembered the task for 21 weeks, through 7.25 months of age, after the periodic reminders. At that point, the experiment was discontinued because infants outgrew the task. Because periodic reminders maintained the memories of two equivalent tasks from 2 months to 2 years of age, the entire period presumably characterized by infantile amnesia, it seems likely that periodic reminders would also maintain a single memory over the same period, if not longer.

The preceding evidence casts serious doubt on popular accounts of infantile amnesia (see section 2.36.5). As long as infants periodically encounter an appropriate nonverbal reminder, their memory of an early experience will be maintained. Thus, whether or not an early experience will be remembered later is determined only by whether or not an appropriate reminder is periodically available in nature. In essence, the ultimate source of infant forgetting resides in the structure of the environment, not in the structure of the brain.

## 2.36.4 Ontogenetic Changes

### 2.36.4.1 Forgetting

Because adults of all species remember for so long, animal researchers have had to study forgetting with immature organisms. The first systematic study of the ontogeny of memory documented that forgetting by infant rats was inversely related to age (Campbell and Campbell, 1962). A parallel study with human infants, modeled after the Campbell and Campbell study, yielded the same result (Hartshorn et al., 1998b). Between 2 and 18 months, infants of all ages exhibited equivalent retention after the shortest test delay, but as the retention interval progressively increased, the younger infants forgot first (**Figure 13**).

The magnitude of the difference in retention between 2 months (1–2 days) and 18 months (13–14 weeks) has two major implications for interpretations of how different variables affect retention at different ages. First, effects on retention must be expressed in relative rather than absolute terms. Whereas 5 days is the longest interval that operantly trained 3-month-olds typically remember, for example, 5 days is a trivial retention interval for 18-month-olds. Second, age effects should not be expected after a short retention interval. Thus, claims that particular variables have no age effects must be treated skeptically unless the effects were also assessed at later points along the forgetting function.

Infants, like adults, forget and retrieve different memory attributes at different rates (Riccio et al., 1994). In operant and deferred imitation tasks, for example, infants forget object color faster than object form (Bhatt and Rovee-Collier, 1996; Hayne et al., 1997). They also forget the specific details of the training mobile before they forget its general features (Rovee-Collier and Sullivan, 1980), and after forgetting, a memory prime recovers its general features before its specific details (Rovee-Collier and Hayne, 1987). One day after priming, infants respond to both a novel test mobile and the original one; 3 days later, they discriminate the mobiles and respond only to the original one. This result is consistent with other evidence that more accessible memories are retrieved faster (see the section 2.36.4.2).

### 2.36.4.2 Accessibility

Memories that are inaccessible but available can still be retrieved; memories that are both inaccessible and unavailable cannot (Tulving, 1983). In both infants and adults, the rapidity with which a memory is retrieved is directly related to its accessibility and inversely related to both the strength or number of cues required to retrieve it and the length of time it has been forgotten. An important consequence of retrieving a memory is an increase in its accessibility (*See* Chapter 2.16). Paradoxically, after a less accessible memory is retrieved, both infants and adults subsequently remember it longer (Schmidt and Bjork, 1992).

Joh et al. (2002) found that the minimum duration of exposure to an effective prime is a linearly increasing function of how long the memory had been forgotten. At 3 months of age, when the memory had been forgotten for 1 day, the minimum duration of priming was 7.5 s; when it had been forgotten for 1

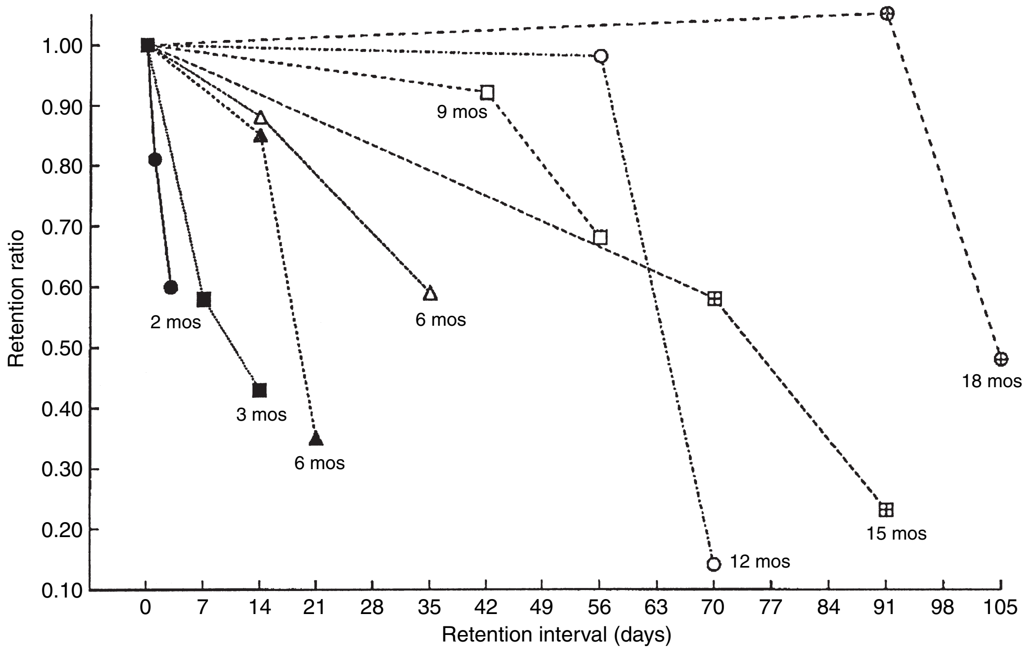


**Figure 13** Forgetting as a function of infant age and test delay. Mean retention ratios of independent groups of infants between 2 and 18 months of age who were trained for 2 consecutive days in the mobile task (2–6 months) or the train task (6–18 months) and received an immediate retention test after the conclusion of acquisition on day 2. Six-month-olds were trained and tested in both tasks. Infants of each age received a delayed recognition test after different retention intervals until, as shown in the last point on each curve, they exhibited no retention. From Hartshorn K, Rovee-Collier C, Gerhardstein P, et al. (1998b) The ontogeny of long-term memory over the first year-and-a-half of life. *Dev. Psychobiol.* 32: 69–89.

week, the minimum duration was 120 s; and when it had been forgotten for 2 weeks, the minimum duration was 180 s. The finding that a longer prime is required to reactivate a memory that has been forgotten longer is theoretically important. In the past, there was no way to measure the accessibility of a memory that was not expressed. These data indicate that the minimum duration of exposure to a prime that can reactivate a latent memory is a direct measure of its accessibility.

A research problem with important applied and theoretical implications concerns manipulations that increase the accessibility of a forgotten memory. Because the latency of response to a memory prime (the priming latency) decreases logarithmically over the first year of life (Hildreth and Rovee-Collier, 1999), it is tempting to attribute the increased accessibility to maturational changes in the nervous system. Hayne et al. (2000b), however, reported that two reactivations decreased the priming latency of 3-month-olds from 24 h to 1 h, which is the typical priming latency of 6-month-olds given one reactivation. This result indicated that priming latency is experientially rather than maturationally based. They concluded that prior priming increased the accessibility of the forgotten memory.

Because prior priming increased the accessibility of a memory by decreasing priming latency (Hayne et al., 2000b), Bearce and Rovee-Collier (2006) hypothesized that prior priming would also increase its accessibility by reducing the minimum duration of exposure to the second prime. It did. The forgotten memory could be reactivated by a briefer prime after it had been primed before.

For infants initially trained between 3 and 18 months of age, the minimum duration of exposure to an effective prime presented 1 week after forgetting decreases logarithmically from 2 min at 3 months of age to 1.5 s at 18 months (**Figure 10**, circles; Hsu et al., 2005). In priming studies with adults, Schacter et al. (1991) reported that a 1-s exposure was not long enough to produce a priming effect, but a 5-s exposure was. Taken together, these findings indicate that successful priming of a preexisting memory representation requires attention that is longer than a mere glance, which takes 1 s. Even though exposure durations decreased by six log steps between 3 and 18 months, infants of all ages forgot twice as fast after a minimum-duration prime as after a full-length one. Nonetheless, the total period over which infants given a minimum-duration prime could remember the training memory was still quite considerable, exceeding 5.5 months at the oldest age (**Figure 10**, circles).

These findings reveal that the minimum duration of exposure to an effective prime is the currency by which the accessibility of memories can be psychophysically scaled. That is, all latent memories that can be activated by primes of the same minimum duration are equally accessible. This principle applies to all memories irrespective of subject age, time since forgetting, memory content, speed of processing, number of prior retrievals, spacing of successive retrievals, and so forth.

### 2.36.4.3 Context

The incidental context refers to relatively invariant aspects of the setting in which an event occurs that do not affect the characteristics or demands of the task. Studies with animals and human adults have found that the context provides additional retrieval cues for the target memory (Riccio et al., 1984). Relatively little attention has been paid to the role of context in infant memory. This neglect has reflected the widespread assumption that infants' brains are too immature to store information about the place where learning occurs (e.g., Nelson, 1995). This assumption, however, is incorrect. Even 3-month-olds encode numerous aspects of the incidental training context, including location (room in home, laboratory), the immediate visual surroundings (a colored-and-patterned cloth covering the sides of the crib), the experimenter (social context), an ambient odor (Rubin et al., 1998), and background music (Fagen et al., 1997).

In order to assess contextual specificity at the same relative points along the forgetting functions of differently aged infants, Hartshorn et al. (1998a) compared retention at the first, middle, and last points on the forgetting functions of 3-, 6-, 9-, and 12-month-olds (see section 2.36.4.1). They found that a change in the testing context impaired retention only after delays near the end of the forgetting function at all ages except 6 months, when it impaired recognition only after relatively short delays. The latter result was attributed to infants' heightened sensitivity to context preceding independent locomotion (Borovsky and Rovee-Collier, 1990). Apparently, the context disambiguates infants' memory of the training cue when it becomes fuzzy and facilitates its recognition (Bouton and Bolles, 1985). The deleterious effect of a context change on recognition is overridden at 3 and 6 months of age by training infants in a different context each day (Amabile and Rovee-Collier, 1991; Rovee-Collier and DuFault, 1991).

After delays so long that the memory has been forgotten, if the memory has been reactivated in the original context, then infants can recognize the training cue in a different test context 24 h later by 9 months of age. By 12 months of age, the memory can also be reactivated in a different context (DeFrancisco, in press). Thereafter, reactivated memories become increasingly less context dependent with age. Thus, infants can transfer what they learn from one place (e.g., nursery school) to another (e.g., home) if asked to do so before too much time has elapsed.

Deferred imitation also increasingly generalizes across physically different contexts with age. Six-month-olds exhibit 24-h deferred imitation when either the test room or the mat they sit on during testing is different from the room or mat present during modeling but exhibit no deferred imitation when both differ (Learmonth et al., 2004). By 9 months, infants generalize when both the floor mat and the room differ. Also, a global context change (e.g., laboratory vs. home) impairs 24-h deferred imitation at 6 months but not at 12 and 18 months after test delays up to 28 days (Hanna and Meltzoff, 1993; Hayne et al., 2000a). Learmonth et al. (2005) found that a novel tester (the social context) disrupted 24-h retention of deferred imitation from 6 to 18 months of age, but preexposure to the novel tester in their home 2 days earlier allowed infants of all ages to generalize imitation. This finding parallels findings from operant studies with infants that novelty inhibits responding. These findings reveal that the similarity between the conditions of encoding and retrieval – not whether the task is deferred imitation or operant conditioning – determines whether young infants generalize.

Recent research on the renewal effect provides evidence that 3-month-olds can also associate the context with experimental contingencies (Cuevas et al., 2005). The renewal effect was originally described by Bouton and Bolles (1979) as the recovery (renewal) of acquisition performance when the contextual cues that were present during extinction are removed. Infants learned to kick to move the mobile in the presence of a distinctive context

(context A) and received an extinction manipulation (kicks did not move the mobile) with the original mobile in a different context (context B). Twenty-four hours later, infants tested with the original mobile in either the acquisition context (context A) or a neutral context (context C) exhibited retention, but infants tested in the extinction context (context B) exhibited none. Thus, the reduction of learned behavior via an extinction procedure in infants, as in adults, is context specific: In contexts other than the extinction context, infants will resume the behavior that was previously reinforced.

## 2.36.5 Latent Learning

Infants learn an enormous amount of information by merely observing their surroundings, but what they learn remains latent until they have a response and an opportunity to express it. Brogden (1939) introduced the sensory preconditioning (SPC) paradigm to study the latent learning of associations between neutral stimuli. The SPC paradigm has three phases. In phase 1, two stimuli (A, B) are repeatedly exposed in close temporal or spatial contiguity; in phase 2, a distinctive response is trained to one of the stimuli (A→R1); and in phase 3, the subject is tested with the other stimulus (B). The transfer of responding to the untrained stimulus (B→R1) but not to an equally familiar but unpaired stimulus is taken as evidence that an association was formed between A and B during the phase 1. Because the association that individuals form during phase 1 remains latent until it is expressed in phase 3, SPC is a form of behaviorally silent learning.

In the first infant study of SPC, Boller (1997) found that simultaneously preexposing 6-month-olds to two cloth panels (contexts) for 1 h daily for 7 days (phase 1) enabled them to associate the contexts. Twenty-four hours after phase 1, she operantly trained infants in one of the contexts (phase 2) and tested them in the other context 24 h later (phase 3). These infants transferred conditioned responding to the other context, but infants who were exposed to the contexts unpaired in phase 1 did not. Using a deferred imitation task, Barr et al. (2003) repeated Boller's procedure and preexposed 6-month-olds to puppets A and B either paired or unpaired for 1 h daily for 7 consecutive days (phase 1), modeled the target actions on puppet A 24 h later (phase 2), and tested infants with puppet B 24 h after that (phase 3). During the deferred imitation test, only the paired preexposure group imitated the target actions on puppet B. The same result was obtained when phase 1 lasted 2 days instead of 7.

Cuevas et al. (2006b) demonstrated that 6-month-olds could form an association between two objects that were neither physically present nor had ever occurred together. The association was formed when the memory representations of those objects were simultaneously activated by associated cues that the infants noticed. In phase 1, infants were exposed simultaneously to hand puppets A and B to establish an association between them. In phase 2, infants were trained to kick to move a crib mobile in a distinctive context to establish a mobile-context association. In phase 3, infants were exposed to puppet A in the distinctive context to establish a puppet B–mobile association. Presumably, puppet A would retrieve its associated memory of puppet B, and the distinctive context would retrieve its associated memory of the mobile. When the memory representations of puppet B and the mobile were simultaneously activated, then infants formed a new association, even though neither object was physically present.

Cuevas et al. subsequently demonstrated three target actions on puppet B to provide infants with an overt, measurable behavior that they could use to express the association. Typically, 6-month-olds remember the deferred imitation task for 1 day but not 3 days (Barr et al., 1996, 2001; **Figure 14**, solid circles), and they remember the mobile task for 14 days (Hill et al., 1988; **Figure 14**, triangles). If 6-month-olds had associated puppet B and the mobile *in absentia*, however, then they would be expected to imitate the actions on puppet B after the same test delays that they remember the mobile task. In fact, independent groups of infants successfully imitated the target actions on puppet B after delays up to 2 weeks, the same duration for which they remember the mobile (**Figure 14**, open circles). Two association control groups failed to imitate on puppet B even 1 week later (**Figure 14**, squares). These findings reveal that young infants form specific and enduring associations between the memory representations of stimuli that are simultaneously activated.

Townsend (2006) found that 6-month-olds are able to associate two puppets that they have never seen together. In phase 1, infants were preexposed to either two or three different pairs of puppets on 2 or 3 consecutive days (A–B, B–C or A–B, B–C, C–D; respectively). One day following their last exposure,

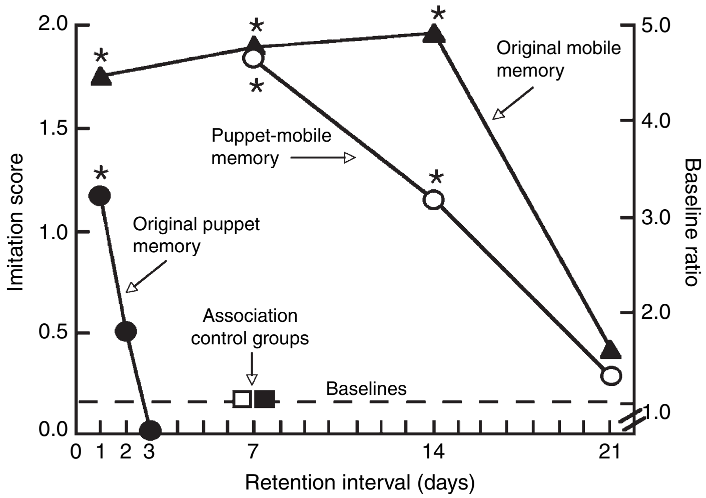


**Figure 14** Mean imitation-test score (left *y*-axis) and mean baseline ratio, the index of operant retention (right *y*-axis), as a function of the retention interval. The deferred imitation function for the three experimental groups that associated the memory representations of puppet B and the mobile is presented along with the original deferred imitation function and the forgetting function for the operant mobile task. Also shown is the test performance of two association control groups. The dotted line indicates the mean base rate (baseline control group) for spontaneous production of the target actions in the deferred imitation task and the theoretical baseline for the mobile task. Asterisks indicate that test performance significantly exceeded the base rate or the theoretical baseline. Note that the form of the retention function of experimental groups in the deferred imitation task mirrors the form of the retention function of infants in the mobile task. Reprinted with permission from Cuevas K, Rovee-Collier C, and Learmonth AE (2006b) Infants form associations between memory representations of stimuli that are absent. *Psychol. Sci.* 17: 543–549. Copyright © 2006 by the Association for Psychological Science.

the target actions were modeled on the final puppet (C or D; phase 2). When tested with puppet A 24 h later (phase 3), infants in both groups imitated the modeled actions, whereas those tested with a novel puppet (puppet E) did not. Thus, 6-month-olds had apparently associated two puppets (A and C or D) that were never presented together. Infants who were preexposed to puppets A and B unpaired or to puppet B alone after the puppet A–B association was formed (an extinction procedure) did not imitate the modeled actions on puppet A, confirming that the A–B link was necessary for imitation.

Simultaneously preexposing two stimuli in phase 1 of SPC results in their association between 3 and 9 months of age (Barr et al., 2003; Campanella and Rovee-Collier, 2005; Bullman et al., 2006), but at 15 months, the same preexposure regimen is less successful (Bullman et al., 2006). Cuevas et al. (2006a) found that the extent of temporal contiguity required for two stimuli to be associated decreased with age from only simultaneous preexposure at 6 months to only sequential preexposure at 15 months. This result resembles age-related increases in associative memory in delay-of-reinforcement studies with infants.

Subsequent research has examined how long infants can remember an association before they finally express it. After one preexposure session at 6–9 months, infants remember the association between two puppets for only 2–3 days. After two preexposure sessions, infants remember the association for 1 week at 6 months and 2 weeks at 9 months (Bullman et al., 2006). The basis for the retention benefit afforded by the additional session results from the additional retrieval at the outset of session 2 and not from the longer exposure time afforded by two sessions. When the total duration of the two sessions was the same as that of one session, infants still remembered longer. These findings reveal that new learning acquired via mere observation can remain latent for a substantial period before it is finally used.

In the preceding studies, infants learned an association (correlation) between two different objects when they repeatedly saw those objects together, irrespective of the experimental paradigm within which they exhibited that knowledge. In all instances, however, the association that infants had picked up by merely looking remained latent until they were subsequently given an opportunity to demonstrate that knowledge through their direct actions.

## 2.36.6 Interference and Memory Updating

Retroactive interference is rare or nonexistent in studies of infant visual recognition memory (for review, see Rose et al., 2007) but common in conditioning studies of infant long-term memory (Rossi-George and Rovee-Collier, 1999; for review, see Rovee-Collier and Boller, 1995). Three-month-olds who were exposed to a novel mobile immediately after training, for example, recognized it but not the original one 24 h later. With the passage of time, the retroactive interference dissipated, and infants again recognized only the original mobile 48 h later (Gulya et al., 2002). In serial learning studies with adults, a recency effect after short test delays and a primacy effect after longer ones is also common.

Because we have never observed an instance of modification or updating that was not also accompanied by response suppression to the original cue, we conclude that retroactive interference is functionally adaptive, enabling memory updating. When responding to the original cue is suppressed and organisms respond to the more recently encountered one, if that recent cue is also predictive, then the original memory is modified or updated. If response suppression is necessary for subjects to respond to a recently encountered stimulus, then the opportunity for memory updating may be over when responding to the original stimulus resumes. Because retroactive interference dissipates if a new cue is not encountered, however, the time window within which updating can occur also decreases until the details of the original cue are forgotten (Rovee-Collier et al., 1994) or the memory is reactivated later (Galluccio and Rovee-Collier, 2005).

Suppressing response to the original stimulus is evidence of retroactive interference, which is temporary. Responding to a recently exposed stimulus instead of the original one, however, is evidence that the memory was permanently modified. Retroactive interference is common at the beginning of the retention interval, when the details of the original stimulus are highly memorable, whereas modification occurs readily at the end of the retention interval, when the details of the original stimulus have been forgotten. Reactivated memories are resistant to modification shortly after forgetting (Boller and Rovee-Collier, 1994; Galluccio, 2005) but are more readily modified when reactivation approaches its upper limit. At 3 months, forgetting is complete in 6 days. One week after training, exposure to a novel mobile immediately after reactivation did not affect infants' recognition of the original mobile; 2 weeks afterward, it interfered with recognition of the original one; and 4 weeks afterward (the upper limit of reactivation at 3 months), it both interfered with recognition of the original mobile and modified the reactivated memory, replacing the memory attributes of the original mobile with those of the novel one (Galluccio and Rovee-Collier, 2005). Findings that both original and reactivated memories are initially resistant to modification but become more malleable when they are older suggest that the same basic mechanism underlies the malleability of original and reactivated memories.

## 2.36.7 Spacing Effects

A general rule in the memory literature is that greater spacing between successive items during training (associative memory) produces memories that are more enduring (Cohen, 1985). The classic retention advantage of distributed over massed training (Crowder, 1976; Glenberg, 1979; Schmidt and Bjork, 1992) has also been obtained with infants. Using a visual recognition memory task. Cornell (1980) showed 5- to 6-month-olds a pair of identical photos of people of one sex for four trials and then tested them after delays of 5 s, 1 min, 5 min, or 1 h with a previously exposed photo paired with a photo of a person of the opposite sex. He found that greater spacing between successive items prolonged infants' retention. When intertrial intervals were 3 s (massed condition), infants recognized the familiar photo only after the 5-s delay; when intertrial intervals were 1 min (distributed condition), they recognized it after all test delays. Using the operant mobile task, Vander Linde et al. (1985) trained 2-month-olds for three 6-min sessions (distributed condition) or one 18-min session (massed condition). Infants given massed training remembered for 1 day, but infants given distributed training remembered for 2 weeks.

Recent research on spacing effects has focused on the interval between successive events (retentive memory) after the first event has been acquired. This research has been conducted within the conceptual framework of the time window construct, which specifies the conditions in which two successive events are integrated (Rovee-Collier, 1995). A time window is a limited period that begins with the onset of an event and ends when the event is forgotten. It specifies when a second event can be integrated with the memory of the first one and when it cannot. New information encountered while the time window is open can be integrated with the initial event; information encountered after it has closed will be treated as unique. The integration is accomplished when the new event retrieves the representation of the initial event into primary or active memory. The time window construct specifies that each retrieval of a memory expands the time window (i.e., increases the period within which it can be retrieved again). Finally, the effects of retrieving the memory of the initial event at different points within the time window are nonuniform; retrieving it near the end of the time window expands the width of the time window more than retrieving it closer to when the time window opens.

In the first time-window study, Rovee-Collier et al. (1995) trained 3-month-olds in the mobile task for two sessions spaced by 1, 2, 3, or 4 days and tested them 8 days after session 1. The control group received session 1 only and the test. Groups exhibited significant retention when sessions were separated by 1–3 days. The group whose two sessions were separated by 4 days and the one-session control group exhibited no retention. Thus, the time window for integrating successive training sessions closed after 3 days. When the second session occurred after the time window closed, it was treated like a first-time event. In a follow-up study, groups received session 2 either inside the time window (2 days after session 1) or outside the time window (4 days after session 1) and a reactivation reminder 2 weeks later. Because memory reactivation requires two training sessions to be successful (Boller and Rovee-Collier, 1992; Richardson et al., 1993; Hayne et al., 2003), infants were expected to exhibit renewed retention after priming only if sessions 1 and 2 had been integrated. In fact, infants who received session 2 inside the time window exhibited retention, but infants who received session 2 outside the time window exhibited none. These results provide convergent evidence that successive events are integrated only if the second event occurs within the time window.

Hsu (2007) used the operant train task to study time window effects in infants between 6 and 18 months of age. The duration for which infants remembered a single training session defined the width of the time window at each age. Despite vast differences in the absolute durations of retention across ages, the pattern of results was remarkably uniform (**Figure 15**). Infants given session 2 just inside the time window remembered longer than infants given only one session, but infants given session 2 just outside the time window behaved as if they received only one session. Additionally, infants whose second session occurred at the end of the time window remembered longer than infants whose second session occurred at the beginning of the time window, 1 day after session 1.

The time window construct also predicts that retrieving the memory of the first event progressively later in its time window will produce an increasingly greater retention benefit. Using a reinstatement procedure, Galluccio and Rovee-Collier (2006) tested this prediction with 3-month-olds. Because 3-month-olds remember the mobile task for 5 days, they gave infants a single 3-min reinstatement 0, 3, or 5 days after mobile training. At the beginning of the time window (day 0), reinstatement afforded only a small retention benefit, 1 additional day. In the middle of the time window (day 3), reinstatement yielded a retention benefit of 5 additional days, or twice the duration of original retention. At the end of the time window (day 5), reinstatement yielded a retention benefit of 16 additional days, a duration of retention more than four times longer than 3-month-olds otherwise remember (**Figure 16**). The exponential increase in the retention benefit as a result of the timing of the reinstatement within the time window was particularly remarkable considering that the reinstatement lasted only 3 min, it was the same for all reinstatement groups, and the timing difference between the final reinstatement groups was only 2 days.

Because young infants' memories are so short-lived relative to the memories of older individuals, the consequences of the timing of a reinstatement within the time window are particularly dramatic. However, the differential retention benefit of presenting a reinstatement late in the time window is not unique to either the operant mobile task or 3-month-olds. A similar effect was obtained in a deferred imitation study with 6-month-olds. At 6 months, infants who imitated the actions immediately after the demonstration, when the time window opened, could defer imitation for 1 but not 2 days (Barr et al., 2001). In contrast, infants who first imitated the actions 1 day later, at the end of the time window, deferred imitation for 10 days after the demonstration (Barr et al., 2005).

Actively imitating the actions was not why infants' retention increased tenfold; infants who merely witnessed an adult model the actions again for 30 s 1 day later also deferred imitation after 10 days. Because

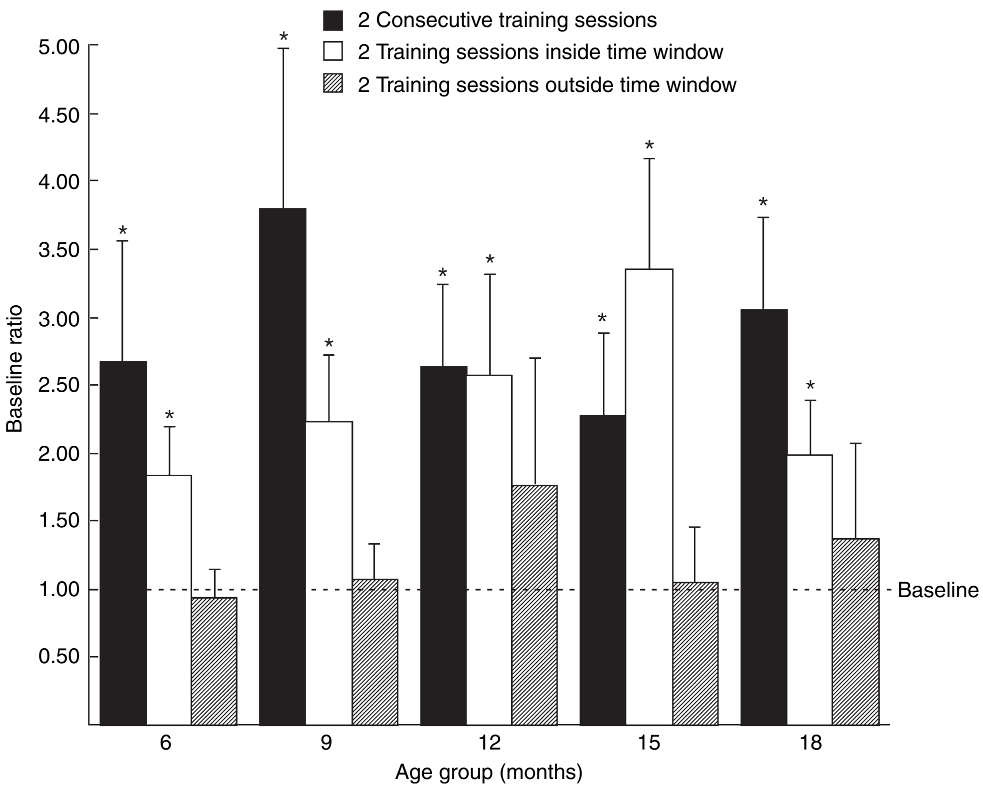


**Figure 15** Mean baseline ratios of independent groups of 6-, 9-, 12-, 15-, and 18-month-olds who received a second training session either inside (black bars, white bars) or outside (gray bars) the time window (i.e., before or just after infants forgot the first training session). Infants given session 2 just inside the time window (white bars) remembered longer than infants who were given only one session, but infants given session 2 just outside the time window did not. The dotted line indicates the theoretical baseline ratio of 1.00 (i.e., no retention). An asterisk indicates significant retention. Vertical bars indicate + 1 SE. From Hsu VC (2007) *Time Window Effects on Retention over the First Year-and-a-Half of Life.* PhD Thesis, Rutgers University, New Brunswick, NJ.

6-month-olds who observe the original demonstration for 30 s cannot defer imitation 1 day later (Barr et al., 1996), merely retrieving the memory at the end of the time window prolonged its retention. In a follow-up experiment, 6-month-olds who repeatedly retrieved the memory at or near the end of the expanding time window on days 1, 10, 30, and 70 still exhibited significant deferred imitation after 10 weeks. Whether they might have done so after a longer delay was not determined. Given that infants otherwise exhibit deferred imitation of the same modeled actions for 1 day, this finding is compelling evidence of the effects of repeated retrievals near the end of the time window.

In a recent study, 6-month-olds' memory of the demonstration was associated with the 'retrieved' memory of the operant train task (Rovee-Collier and Barr, 2006). Six-month-olds first learned to move the train by lever pressing, and 7 days (the midpoint of the time window for the train task) or 14 days (the end of its time window) later, the target actions were modeled on a puppet in the presence of the stationary train. After both delays, the sight of the train cued retrieval of the memory of the train task, and the demonstration was then associated with the updated status of its memory representation. When the demonstration was associated with the retrieved memory 7 days after operant training, infants remembered the train task for 4 weeks instead of 2 weeks, and they also deferred imitation on the puppet for 4 weeks instead of 1 day. When the demonstration was associated with the retrieved memory 14 days after operant training, infants remembered the train task for 8 weeks instead of 2 weeks and deferred imitation on the puppet for 6 weeks instead of 1 day. A no-association control group that saw the demonstration and the stationary train unpaired 7 days after operant training failed to defer imitation 1 week later but continued to remember the train task for 14 days.

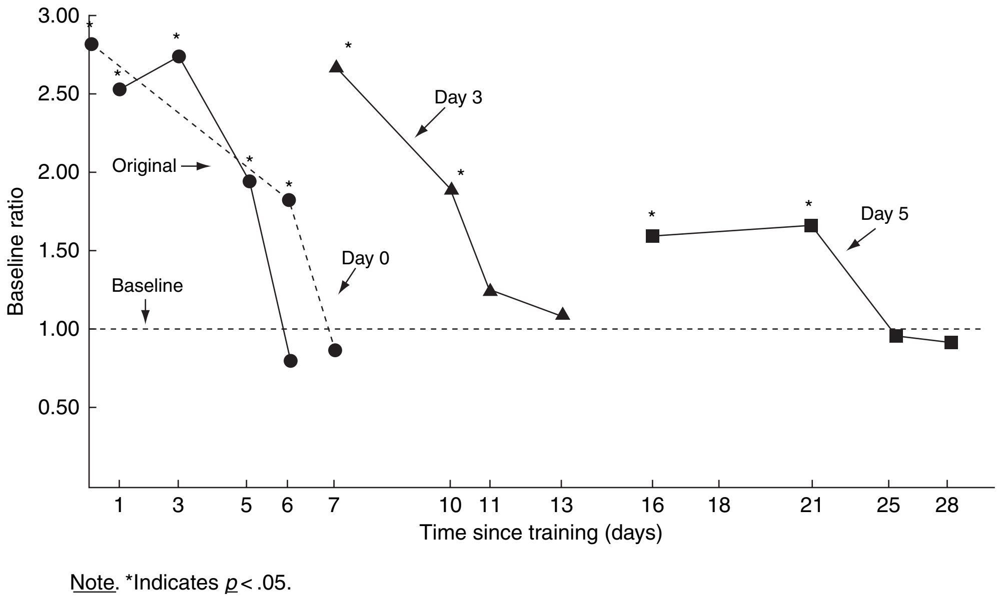


**Figure 16** Mean baseline ratios of independent groups of 3-month-olds whose retention was tested after increasing delays since training (the simple forgetting function: circles, solid lines) and after receiving a reinstatement on day 0 (circles/dashed lines), day 3 (triangles/solid lines), and day 5 (squares/solid lines). The first point on the day-0 function is the retention of group 0/6 at the end of training, immediately before the reinstatement was administered. An asterisk indicates that a group exhibited significant retention. From Galluccio L and Rovee-Collier C (2006) Nonuniform effects of reinstatement within the time window. *Learn. Motiv.* 37: 1–17. Copyright © 2006 by Elsevier Inc.

What does all of this mean? Clearly, memory retrieval – particularly later in the time window – has a huge effect on the memory of what was retrieved as well as on the memory of what is associated with it, and the effects of multiple retrievals are even greater. Because most memory retrievals in real-world settings are probably latent, as are most of the associations into which retrieved (activated) memories enter, the extent of their contribution to the growth of the early knowledge base can never be known.

Time window effects have also been reported in infant studies of categorization, eyewitness testimony, postevent information, memory modification, and language acquisition (for review, see Rovee-Collier, 1995; Hsu, 2007). Although the applicability of the time window construct is not constrained by age or stage of development, its impact on the retention of very young infants, whose retention is initially so brief, may be most obvious.

## 2.36.8 Implicit and Explicit Memory

Many psychologists believe that adults possess two functionally independent and anatomically different memory systems that mature hierarchically (e.g., Schacter and Moscovitch, 1984; Bauer et al., 2007). By this account, infants possess only the primitive memory system (implicit memory) until late in their first year, when the higher-level system (explicit memory) matures. Proponents of dichotomous memory systems interpret functional dissociations as evidence for different memory systems (e.g., Tulving, 1983; Squire, 1987). A functional dissociation is seen when the same experimental manipulation that produces impaired performance by brain-damaged amnesic adults on recall or recognition tests does not affect their performance on priming tests. Recall and recognition tests are thought to tap the explicit memory system, which presumably processes information about a specific past experience; in contrast, priming tests are thought to tap the implicit memory system, which presumably processes information only about skills and procedures that can become habitual or automatized and general facts. A large literature has now amassed, however, documenting that even 3-month-olds exhibit all of the same functional dissociations on recognition and priming (reactivation) tests as adults (for review, see Rovee-Collier et al., 2001).

For proponents of dichotomous memory systems, however, the defining characteristic of explicit memory is the conscious awareness of previously experiencing the event (Tulving, 1985), and they use conscious awareness to distinguish explicit from implicit memory. On a priming test, for example, amnesics (who presumably possess only an implicit memory system) respond with a word from a list they had just studied while being unaware that they had studied it. Amnesics also fail deferred imitation tests that healthy adults use conscious recollection to perform. As a result, proponents of dichotomous memory systems assume that infants who exhibit deferred imitation must also use conscious recollection to do so. Based on this assumption, they use deferred imitation as a benchmark that the explicit memory system is functionally mature (McDonough et al., 1995; Bauer, 1996; Bauer et al., 2007). If successful deferred imitation constitutes evidence that the explicit memory system has matured, however, then it must be mature by 3 months of age. Recall that infants who saw target actions modeled on a hand puppet at 3 months of age successfully imitated them once they were motorically capable of performing them (Campanella and Rovee-Collier, 2005).

Evidence that 3-month-olds exhibit both functional dissociations and deferred imitation disputes the notion that implicit and explicit memory develop hierarchically during the infancy period. If there are two memory systems, then they must develop in parallel from early in infancy. We note, however, that because scientists can neither define consciousness nor state what the function of consciousness in memory might be, it is not yet clear how memories that have it might be different from memories that do not (Willingham and Preuss, 1995).

## 2.36.9 Infantile Amnesia

Infantile amnesia refers to the fact that most people cannot remember events that occurred before the age of 3 or 4 (but see Fivush and Hamond, 1990; Usher and Neisser, 1993). There has been little agreement about the basis or even the ubiquity of this phenomenon (Mandler, 1990). Common explanations of infantile amnesia include the classical psychoanalytic account of repressed infantile memories, the immaturity of the infant's brain that prevents the encoding, storage, and retrieval of memories over the long term, young infants' exclusive reliance on a primitive memory system, and rapid forgetting within the infancy period. Most of these explanations were discounted by evidence reported earlier in this chapter.

Additionally, verbal cues are usually presented as retrieval cues in studies of infantile amnesia. The common conclusion is that "virtually no early memories slip through the barrier" (Nelson, 1990: p. 306). Simcock and Hayne (2002 see also Simcock and Hayne, 2003) questioned whether the development of language actually blocked early memories. To answer this, they developed a memory task using the Magic Shrinking Machine (**Figure 17**), in which 27-, 33-, and 39-month-olds participated in a highly unique, multistep event in their homes. Children learned a sequence of five target actions: Pull a lever to activate an array of lights and turn the machine on, pick a toy from the toy case (ball, teddy bear), drop the toy in a chute on top of the machine, turn the handle on the side of the machine (which produced noise and music from inside the box), and retrieve a smaller version of the toy from the front of the machine. Either 6 or 12 months later, infants' memory of the event was assessed with both verbal and nonverbal measures. Children of all ages exhibited retention on both measures after both test delays, but their memory performance on nonverbal measures was consistently superior. Importantly, children's verbal reports during the long-term test reflected their verbal skills at the time of encoding, even though the words that could be used to verbally recall the event were in their vocabularies at the time of testing. Thus, children with language could remember the prior event that had been encoded preverbally, but they could not translate what they had encoded into words.

Because the fundamental principles of memory processing in human infants and adults are the same, we conclude that the phenomenal experience of infantile amnesia can be understood within the existing framework of normal memory process. First, the encoding specificity principle (Tulving and Thomson, 1973) states that a match between the encoding and retrieval contexts is critical for retrieval. In infancy, this is especially true after long delays (Hartshorn et al., 1998a). As a result, the shift from nonverbal to verbal retrieval cues dramatically lessens the probability that a memory encoded in infancy would be retrieved later in life. From this perspective, words are retrieval cues whose status is no different than that of other potential retrieval cues.

Second, even if an appropriate retrieval cue were to recover an early memory later in life, a person

**Figure 17** A child participating in the memory task with the Magic Shrinking Machine. The child places a large toy in a chute on top of the machine, turns the handle on the side of the box (presumably to shrink the toy), opens a side bin (where the shrunken toy has presumably dropped), and retrieves a miniature version of the toy. Photos courtesy of Harlene Hayne and Julien Gross.

would be unlikely to identify it as such. Because reactivated memories that are older are readily updated, for example, they may be impossible to identify as having originated early on (Galluccio and Rovee-Collier, 2005).

Third, as memories of healthy individuals become increasingly remote, they appear to become increasingly disconnected from their original temporal context and more semantic and fact-like (Bayley et al., 2003). Even in infants, specific contextual information is quite fragile and disappears from memories that are older or were previously reactivated (Hitchcock and Rovee-Collier, 1996; Galluccio and Rovee-Collier, 2005). As a result, people might actually remember many early-life events without knowing where or when they occurred. Alternatively, if an early memory was modified after a long delay, then it might differ substantially from the original one (Galluccio and Rovee-Collier, 2005). Even if an early memory were neither updated nor repeatedly retrieved, its recovery is ultimately constrained by the upper limit of reactivation (Hildreth and Hill, 2003; Hsu and Rovee-Collier, 2006).

## 2.36.10 Conclusions

Although the neurological mechanisms (the hardware) that underlie learning and memory change over development, the operating principles (the software) that describe how individuals learn and remember do not. While the same variables and manipulations affect memory processing in the same ways in infants and adults, the temporal parameters of memory processing change dramatically but in an orderly fashion over the infancy period: (1) the duration of retention after original training increases, (2) the duration of retention after reminding increases, (3) the speed of responding to a memory prime increases, (4) the upper limit of reactivation increases, and (5) the minimum duration of exposure to a memory prime decreases. Most if not all of these changes can be produced at younger ages by retrieval experience. While later developments such as verbal and conversational skills, strategies for remembering, and the development of the self-concept may facilitate the efficiency of memory processing, they do not alter the fundamental mechanisms that underlie it.

Recent research with very young infants has expanded our knowledge of infant memory far beyond what was ever imagined possible, with equally dramatic implications for the infant's rapidly burgeoning knowledge base. The findings show that very young infants rapidly form new and relatively enduring associations between stimuli that are physically present in their visual surroundings and even between the activated memory representations of stimuli and events that are not. These new associations become linked with each other and with other members of a complex and rapidly growing associative network. When one member of an association is activated, the activation spreads to other members in the network and indirectly activates them as well. As a result, infants as young as 6 months of age exhibit bidirectional priming (Barr et al., 2002) and transitivity (Townsend, 2006) on deferred imitation tests and use correlated attributes to categorize novel stimuli on delayed recognition tests (Bhatt et al., 2004). The same processes may also be responsible for false memories and behavior that appears insightful in children and adults.

These findings necessitate a major revision in how we think about infant memory. Although some aspects of infant memory processing are age invariant, such as the effects of priming on various independent variables, other aspects of infant memory processing change with experience. Importantly, the fact that these changes are logarithmic and subject to Weber's Law indicates that memory processing is perceptually based. That said, the content of what is retrieved apparently results from activation that spreads nonlinearly through a growing web of associations, most of which will always remain latent. In short, infant memory is like other things in life: nothing is as simple as it once seemed.

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## References

Adler SA, Wilk A, and Rovee-Collier C (2000) Reinstatement versus reactivation effects on active memory in infants. *J. Exp. Child Psychol.* 75: 93–115.

Amabile TA and Rovee-Collier C (1991) Contextual variation and memory retrieval at six months. *Child Dev.* 62: 1155–1166.

Anisfeld M (2005) No compelling evidence to dispute Piaget's timetable of the development of representational imitation in infancy. In: Hurley S and Chater N (eds.) *Perspectives on Imitation: From Neuroscience to Social Science, vol. 2. Imitation Human Development and Culture*, pp. 107–131. Cambridge, MA: MIT Press.

Barr R, Dowden A, and Hayne H (1996) Developmental changes in deferred imitation by 6- to 24-month-old infants. *Infant Behav. Dev.* 19: 159–170.

Barr R, Vieira A, and Rovee-Collier C (2001) Mediated imitation in 6-month-olds: Remembering by association. *J. Exp. Child Psychol.* 79: 229–252.

Barr R, Vieira A, and Rovee-Collier C (2002) Bidirectional priming in infants. *Mem. Cognit.* 30: 246–255.

Barr R, Marrott H, and Rovee-Collier C (2003) The role of sensory preconditioning in memory retrieval by preverbal infants. *Learn. Behav.* 31: 111–123.

Barr R, Rovee-Collier C, and Campanella J (2005) Retrieval protracts deferred imitation by 6-month-olds. *Infancy* 7: 263–283.

Bauer PJ (1996) What do infants recall of their lives? Memory for specific events by one- to two-year-olds. *Am. Psychol.* 51: 29–41.

Bauer PJ (2004) Getting explicit memory off the ground: Steps toward construction of a neuro-developmental account of changes in the first two years of life. *Dev. Rev.* 24: 347–373.

Bauer PJ, Hertsgaard LA, and Wewerka SS (1995) Effects of experience and reminding on long-term recall in children: Remembering not to forget. *J. Exp. Child Psychol.* 59: 260–298.

Bauer PJ, DeBoer T, and Lukowski AF (2007) In the language of multiple memory systems. In: Oakes LM and Bauer PJ (eds.) *Short- and Long-Term Memory in Infancy and Early Childhood*, p. 240. Oxford: Oxford University Press.

Bayley PJ, Hopkins RO, and Squire LR (2003) Successful recollection of remote autobiographical memories by amnesic patients with medial temporal lobe lesions. *Neuron* 38: 135–144.

Bearce KH and Rovee-Collier C (2006) Repeated priming increases memory accessibility in infants. *J. Exp. Child Psychol.* 93: 357–376.

Berlyne DE (1958) The influence of the albedo and complexity of stimuli on visual fixation in the human infant. *Br. J. Psychol.* 49: 315–318.

Best CT (1984) Discovering messages in the medium: Speech and the prelinguistic infant. In: Fitzgerald HE, Lester B, and Yogman M (eds.) *Advances in Pediatric Psychology,* vol. 2, pp. 97–145. New York: Plenum.

Bhatt RS and Rovee-Collier C (1996) Infants' forgetting of correlated attributes and object recognition. *Child Dev.* 67: 172–187.

Bhatt RS, Wilk A, Hill D, and Rovee-Collier C (2004) Correlated attributes and categorization in the first half-year of life. *Dev. Psychobiol.* 44: 103–115.

Boller K (1997) Preexposure effects on infant learning and memory. *Dev. Psychobiol.* 31: 93–105.

Boller K and Rovee-Collier C (1992) Contextual coding and recoding of infant memory. *J. Exp. Child Psychol.* 52: 1–23.

Boller K and Rovee-Collier C (1994) Contextual updating of reactivated memories. *Dev. Psychobiol.* 27: 241–256.

Borovsky D and Rovee-Collier C (1990) Contextual constraints on memory retrieval at six months. *Child Dev.* 61: 1569–1583.

Bouton ME and Bolles RC (1979) Contextual control of the extinction of conditioned fear. *Learn. Motiv.* 10: 445–466.

Bouton ME and Bolles RC (1985) Contexts, event-memories, and extinction. In: Balsam PD and Tomie A (eds.) *Context and Learning*, pp. 133–166. Hillsdale, NJ: Erlbaum.

Brody LR (1981) Visual short-term cued recall memory in infancy. *Child Dev.* 52: 242–250.

Brogden WJ (1939) Sensory pre-conditioning. *J. Exp. Psychol.* 25: 323–332.

Bullman A, Cuevas K, and Rovee-Collier C (2006) *Memory for Associations at 6 and 9 Months of Age.* Paper presented at the annual meeting of the Eastern Psychological Association, Baltimore, MD, March 2006.

Burtt HE (1932) An experimental study of early childhood memory. *J. Genet. Psychol.* 40: 287–295.

Burtt HE (1937) A further study of early childhood memory. *J. Genet. Psychol.* 50: 187–192.

Burtt HE (1941) An experimental study of early childhood memory: Final report. *J. Genet. Psychol.* 58: 435–439.

Campanella J and Rovee-Collier C (2005) Latent learning and deferred imitation at 3 months. *Infancy* 7: 243–262.

Campbell BA and Campbell EH (1962) Retention and extinction of learned fear in infant and adult rats. *J. Comp. Physiol. Psychol.* 55: 1–8.

Campbell BA and Jaynes J (1966) Reinstatement. *Psychol. Rev.* 73: 478–480.

Cohen LB and Gelber ER (1975) Infant visual memory. In: Cohen L and Salapatek P (eds.) *Infant Perception: From Sensation to Cognition, vol. 1. Basic Visual Processes*, pp. 347–404. New York: Academic Press.

Cohen RL (1985) On the generality of the laws of memory. In: Nilsson L-G and Archer T (eds.) *Perspectives on Learning and Memory*, pp. 247–277. Hillsdale, NJ: Erlbaum.

Cornell EH (1979) Infants' recognition memory, forgetting, and savings. *J. Exp. Child Psychol.* 28: 359–374.

Cornell EH (1980) Distributed study facilitates infants' delayed recognition memory. *Mem. Cognit.* 8: 539–542.

Crowder RG (1976) *Principles of Learning and Memory*. Hillsdale, NJ: Erlbaum.

Cuevas K, Learmonth AE, and Rovee-Collier C (2005) *Contextual Determinants of Infant Learning: The Renewal Effect.* Paper presented at the annual meeting of the Eastern Psychological Association, Boston, MA, March 2005.

Cuevas K, Bullman A, and Rovee-Collier C (2006a) *Transitions in the Temporal Parameters of Associative Learning During Infancy.* Paper presented at the annual meeting of the Pavlovian Society, Philadelphia, PA, September 2006.

Cuevas K, Rovee-Collier C, and Learmonth AE (2006b) Infants form associations between memory representations of stimuli that are absent. *Psychol. Sci.* 17: 543–549.

DeFrancisco BS (in press) The specificity of priming effects over the first year of life. *Dev. Psychobiol.*

Deocampo JA and Hudson JA (2003) Reinstatement of 2-year-olds event memory using photographs. *Memory* 11: 13–25.

Diamond A (1990) Rate of maturation of the hippocampus and the developmental progression of children's performance on the delayed non-matching to sample and visual paired comparison tasks. *Ann. NY Acad. Sci.* 608: 394–426.

Diamond A (1995) Evidence of robust recognition memory early in life even when assessed by reaching behavior. *J. Exp. Child Psychol.* 59: 419–456.

Diamond A, Towle C, and Boyer K (1994) Young children's performance on a task sensitive to the memory functions of the medial temporal lobe in adults: The delayed nonmatching-to-sample task reveals problem that are due to non-memory-related task demands. *Behav. Neurosci.* 108: 659–680.

Fagan JF III (1970) Memory in the infant. *J. Exp. Child Psychol.* 9: 217–226.

Fagan JF III (1973) Infants' delayed recognition memory and forgetting. *J. Exp. Child Psychol.* 16: 424–450.

Fagen JW and Rovee-Collier C (1983) Memory retrieval: A time-locked process in infancy. *Science* 222: 1349–1351.

Fagen JW, Prigot J, Carroll M, Pioli L, Stein A, and Franco A (1997) Auditory context and memory retrieval in young infants. *Child Dev.* 68: 1057–1066.

Fantz RL (1956) A method for studying early visual development. *Percept. Mot. Skills* 6: 13–15.

Fantz RL (1964) Visual experience in infants: Decreased attention to familiar patterns relative to novel ones. *Science* 46: 668–670.

Fivush R and Hamond NR (1990) Autobiographical memory across the preschool years: Toward reconceptualizing childhood amnesia. In: Fivush R and Hudson JA (eds.) *Knowing and Remembering in Young Children*, pp. 223–248. Cambridge: Cambridge University Press.

Fivush R, Kuebli J, and Clubb PA (1992) The structure of events and event representation: A developmental analysis. *Child Dev.* 63: 188–201.

Galluccio L (2005) Updating reactivated memories in infancy: I. Passive- and active-exposure effects. *Dev. Psychobiol.* 47: 1–17.

Galluccio L and Rovee-Collier C (1999) Reinstatement effects on retention at 3 months of age. *Learn. Motiv.* 30: 296–316.

Galluccio L and Rovee-Collier C (2005) Updating reactivated memories in infancy: II. Time passage and repetition effects. *Dev. Psychobiol.* 47: 18–30.

Galluccio L and Rovee-Collier C (2006) Nonuniform effects of reinstatement within the time window. *Learn. Motiv.* 37: 1–17.

Glenberg AM (1979) Component-levels theory of the effects of spacing of repetitions on recall and recognition. *Mem. Cognit.* 7: 95–112.

Gross J, Hayne H, Herbert J, and Sowerby P (2002) Measuring infant memory: Does the ruler matter? *Dev. Psychobiol.* 40: 1–7.

Gulya M, Rossi-George A, and Rovee-Collier C (2002) Dissipation of retroactive interference in human infants. *J. Exp. Psychol. Anim. Behav. Process.* 28: 151–162.

Haith MM (1972) The forgotten message of the infant smile. *Merrill-Palmer Q.* 18: 321–322.

Hanna E and Meltzoff AN (1993) Peer imitation by toddlers in laboratory, home, and day-care contexts: Implications for social learning and memory. *Dev. Psychol.* 29: 701–710.

Hartshorn K (2003) Reinstatement maintains a memory in human infants for 1½ years. *Dev. Psychobiol.* 42: 269–282.

Hartshorn K and Rovee-Collier C (1997) Infant learning and long-term memory at 6 months: A confirming analysis. *Dev. Psychobiol.* 30: 71–85.
Hartshorn K, Rovee-Collier C, Gerhardstein P, et al. (1998a) Developmental changes in the specificity of memory over the first year of life. *Dev. Psychobiol.* 33: 61–78.
Hartshorn K, Rovee-Collier C, Gerhardstein P, et al. (1998b) The ontogeny of long-term memory over the first year-and-a-half of life. *Dev. Psychobiol.* 32: 69–89.
Hayne H (1990) The effect of multiple reminders on long-term retention in human infants. *Dev. Psychobiol.* 23: 453–477.
Hayne H (2004) Infant memory development: Implications for childhood amnesia. *Dev. Rev.* 24: 33–73.
Hayne H (2007) Infant memory development. In: Oakes LM and Bauer PJ (eds.) *Short- and Long-Term Memory in Infancy and Early Childhood*, p. 209. Oxford: Oxford University Press.
Hayne H and Findlay N (1995) Contextual control of memory retrieval in infancy: Evidence for associative priming. *Infant Behav. Dev.* 18: 195–207.
Hayne H and Herbert J (2004) Verbal cues facilitate memory retrieval during infancy. *J. Exp. Child Psychol.* 89: 127–139.
Hayne H, MacDonald S, and Barr R (1997) Developmental changes in the specificity of memory over the second year of life. *Infant Behav. Dev.* 20: 233–245.
Hayne H, Boniface J, and Barr R (2000a) The development of declarative memory in human infants: Age-related changes in deferred imitation. *Behav. Neurosci.* 114: 77–83.
Hayne H, Gross J, Hildreth K, and Rovee-Collier C (2000b) Repeated reminders increase the speed of memory retrieval by 3-month-old infants. *Dev. Sci.* 3: 312–318.
Hayne H, Barr R, and Herbert J (2003) The effect of prior practice on memory reactivation and generalization. *Child Dev.* 74: 1615–1627.
Hildreth K and Hill D (2003) Retrieval difficulty and retention of reactivated memories over the first year of life. *Dev. Psychobiol.* 43: 216–229.
Hildreth K and Rovee-Collier C (1999) Decreases in the response latency to priming over the first year of life. *Dev. Psychobiol.* 35: 276–290.
Hildreth K and Rovee-Collier C (2002) Forgetting functions of reactivated memories over the first year of life. *Dev. Psychobiol.* 41: 277–288.
Hildreth K, Sweeney B, and Rovee-Collier C (2003) Differential memory-preserving effects of reminders at 6 months. *J. Exp. Child Psychol.* 84: 41–62.
Hill WH, Borovsky D, and Rovee-Collier C (1988) Continuities in infant memory development over the first half-year. *Dev. Psychobiol.* 21: 43–62.
Hitchcock DFA and Rovee-Collier C (1996) The effect of repeated reactivations on memory specificity in infants. *J. Exp. Child Psychol.* 62: 378–400.
Howe ML, Courage ML, and Bryant-Brown L (1993) Reinstating preschoolers' memories. *Dev. Psychol.* 29: 854–869.
Hsu VC (2007) *Time Window Effects on Retention over the First Year-and-a-Half of Life.* PhD Thesis, Rutgers University, New Brunswick, NJ.
Hsu VC and Rovee-Collier C (2006) Memory reactivation in the second year of life. *Infant Behav. Dev.* 28: 1–17.
Hsu VC, Rovee-Collier C, Hill DL, Grodkiewicz J, and Joh AS (2005) Effects of priming duration on retention over the first 1½ years of life. *Dev. Psychobiol.* 47: 43–54.
Hudson JA and Sheffield EG (1998) Deja vu all over again: Effects of reenactment on toddlers' event memory. *Child Dev.* 69: 51–67.
Ivkovich D, Collins KL, Eckerman CO, Krasnegor NA, and Stanton ME (1999) Classical delay eyeblink conditioning in 4- and 5-month-old human infants. *Psychol. Sci.* 10: 4–8.
Joh A, Sweeney B, and Rovee-Collier C (2002) Minimum duration of reactivation at 3 months. *Dev. Psychobiol.* 40: 23–32.
Jones HE (1930) The retention of conditioned emotional reactions in infancy. *J. Genet. Psychol.* 37: 485–498.
Kandel ER and Hawkins RD (1992) The biological basis of learning and individuality. *Sci. Am.* 267: 79–86.
Kimble GA (1947) Conditioning as a function of the time between conditioned and unconditioned stimuli. *J. Exp. Psychol.* 37: 1–15.
Learmonth AE, Lamberth R, and Rovee-Collier C (2004) Generalization of deferred imitation during the first year of life. *J. Exp. Child Psychol.* 88: 297–318.
Learmonth AE, Lamberth R, and Rovee-Collier C (2005) The social context of imitation in infancy. *J. Exp. Child Psychol.* 91: 297–314.
Lewis M (1967) The meaning of a response, or why researchers in infant behavior should be oriental metaphysicians. *Merrill-Palmer Q.* 13: 7–18.
Liston C and Kagan J (2002) Memory enhancement in early childhood. *Nature* 419: 896.
Little AH (1970) *Eyelid Conditioning in the Human Infant as a Function of the Interstimulus Interval.* MS Thesis, Brown University, Providence, RI.
Little AH, Lipsitt LP, and Rovee-Collier C (1984) Classical conditioning and retention of the infant's eyelid response: Effects of age and interstimulus interval. *J. Exp. Child Psychol.* 37: 512–524.
Mandler JM (1990) Recall and its verbal expression. In: Fivush R and Hudson JA (eds.) *Knowing and Remembering in Young Children*, pp. 317–330. Cambridge: Cambridge University Press.
Mandler JM (1998) Representation. In: Damon W (ed.) *Handbook of Child Psychology: Cognition Perception, and Language,* vol. 2, pp. 255–308. New York: Wiley.
McDonough L, Mandler JM, McKee RD, and Squire LR (1995) The deferred imitation task as a nonverbal measure of declarative memory. *Proc. Natl. Acad. Sci. USA* 92: 7580–7584.
Meltzoff AN (1985) Immediate and deferred imitation in fourteen- and twenty-four-month-old infants. *Child Dev.* 56: 62–72.
Meltzoff AN (1988) Infant imitation and memory: Nine-month-olds in immediate and deferred tests. *Child Dev.* 59: 217–225.
Meltzoff AN (1995) What infant memory tells us about infantile amnesia: Long-term recall and deferred imitation. *J. Exp. Child Psychol.* 59: 497–515.
Mill JS (1909) Autobiography. In: Eliot CW (ed.) *The Harvard Classics,* vol. 25, p. 7. New York: PF: Collier and Son.
Millar WS (1990) Span of integration for delayed-reward contingency learning in 6- to 8-month-old infants. *Ann. NY Acad. Sci.* 608: 239–259.
Nelson CA (1995) The ontogeny of human memory: A cognitive neuroscience perspective. *Dev. Psychol.* 31: 723–738.
Nelson K (1990) Remembering, forgetting, and childhood amnesia. In: Fivush R and Hudson JA (eds.) *Knowing and Remembering in Young Children*, pp. 301–316. Cambridge: Cambridge University Press.
Overman WH (1990) Performance on traditional matching to sample, non-matching to sample, and object discrimination tasks by 12- to 32-month-old children: A developmental progression. *Ann. NY Acad. Sci.* 608: 365–385.
Pascalis O and de Schonen S (1994) Recognition memory in 3- to 4-day-old human neonates. *Neuroreport* 5: 1721–1724.
Pascalis O, de Haan M, Nelson CA, and de Schonen S (1998) Long-term recognition memory for faces assessed by visual paired comparison in 3- and 6-month-old infants. *J. Exp. Psychol. Learn. Mem. Cogn.* 24: 249–260.

Piaget J (1962) *Play Dreams and Imitation in Childhood*. New York: Norton.

Ramey CT and Ourth LL (1971) Delayed reinforcement and vocalization rates of infants. *Child Dev.* 42: 291–297.

Ratner H, Smith B, and Dion S (1986) Development of memory for events. *J. Exp. Child Psychol.* 41: 411–428.

Revusky S (1971) The role of interference in association over a delay. In: Honig WK and James PHR (eds.) *Animal Memory*, pp. 155–213. New York: Academic Press.

Riccio DC, Richardson R, and Ebner DL (1984) Memory retrieval deficits based upon altered contextual cues: A paradox. *Psychol. Bull.* 96: 152–165.

Riccio DC, Rabinowitz VC, and Axelrod S (1994) Memory: When less is more. *Am. Psychol.* 49: 917–926.

Richardson R, Wang P, and Campbell BA (1993) Reactivation of nonassociative memory. *Dev. Psychobiol.* 26: 1–23.

Rose SA, Feldman JF, and Jankowski JJ (2004) Infant visual recognition memory. *Dev. Rev.* 24: 74–100.

Rose SA, Feldman JF, and Jankowski JJ. (2007) Developmental aspects of visual recognition memory in infancy. In: Oakes LM and Bauer PJ (eds.) *Short- and Long-Term Memory in Infancy and Early Childhood*, p. 153. Oxford: Oxford University Press.

Rossi-George A and Rovee-Collier C (1999) Retroactive interference in 3-month-old infants. *Dev. Psychobiol.* 35: 167–177.

Rovee CK and Fagen JW (1976) Extended conditioning and 24-hr retention in infants. *J. Exp. Child Psychol.* 21: 1–11.

Rovee CK and Rovee DT (1969) Conjugate reinforcement of infant exploratory behavior. *J. Exp. Child Psychol.* 8: 33–39.

Rovee-Collier C (1995) Time windows in cognitive development. *Dev. Psychol.* 51: 1–23.

Rovee-Collier C (1997) Dissociations in infant memory: Rethinking the development of implicit and explicit memory. *Psychol. Rev.* 104: 467–498.

Rovee-Collier C and Barr R (2006) *Representation-Mediated Deferred Imitation by 6-Month-old Infants*. Paper presented at the annual meeting of the Pavlovian Society, Philadelphia, PA, September 2006.

Rovee-Collier C and Boller K (1995) Interference or facilitation in infant memory? In: Brainerd CJ and Dempster FN (eds.) *Interference and Inhibition in Cognition*, pp. 61–103. New York: Academic Press.

Rovee-Collier C and DuFault D (1991) Multiple contexts and memory retrieval at three months. *Dev. Psychobiol.* 24: 39–49.

Rovee-Collier C and Hayne H (1987) Reactivation of infant memory: Implications for cognitive development. In: Reese HW (ed.) *Advances in Child Development and Behavior,* vol. 20, pp. 185–238. New York: Academic Press.

Rovee-Collier C and Sullivan MW (1980) Organization of infant memory. *J. Exp. Psychol.: Hum. Learn. Mem.* 6: 798–807.

Rovee-Collier C, Sullivan MW, Enright MK, Lucas D, and Fagen JW (1980) Reactivation of infant memory. *Science* 208: 1159–1161.

Rovee-Collier C, Griesler PC, and Earley LA (1985) Contextual determinants of infant retention. *Learn. Motiv.* 16: 139–157.

Rovee-Collier C, Adler SA, and Borza MA (1994) Substituting new details for old? Effects of delaying postevent information on infant memory. *Mem. Cognit.* 22: 644–656.

Rovee-Collier C, Evancio S, and Earley LA (1995) The time window hypothesis: Spacing effects. *Infant Behav. Dev.* 18: 69–78.

Rovee-Collier C, Hartshorn K, and DiRubbo M (1999) Long-term maintenance of infant memory. *Dev. Psychobiol.* 35: 91–102.

Rovee-Collier C, Hayne H, and Colombo M (2001) *The Development of Implicit and Explicit Memory*. Amsterdam: John Benjamins.

Rubin GB, Fagen JW, and Carroll M (1998) Olfactory context and memory retrieval in 3-month-old infants. *Infant Behav. Dev.* 21: 641–658.

Schacter DL (1990) Perceptual representation systems and implicit memory: Toward a resolution of the multiple memory systems debate. *Ann. NY Acad. Sci.* 608: 543–567.

Schacter DL (1992) Priming and multiple memory systems: Perceptual mechanisms of implicit memory. *J. Cogn. Neurosci.* 4: 244–256.

Schacter DL and Moscovitch M (1984) Infants, amnesics, and dissociable memory systems. In: Moscovitch M (ed.) *Advances in the Study of Communication and Affect, vol. 9: Infant Memory*, pp. 173–216. New York: Plenum.

Schacter DL, Cooper LA, Delaney SM, Peterson MA, and Tharan M (1991) Implicit memory for possible and impossible objects: Constraints on the construction of structural descriptions. *J. Exp. Psychol. Learn. Mem. and Cogn.* 17: 3–19.

Schmidt RA and Bjork RA (1992) New conceptualizations of practice: Common principles in three paradigms suggest new concepts for training. *Psychol. Sci.* 3: 207–217.

Sheffield EG and Hudson JA (1994) Reactivation of toddlers' event memory. *Memory* 2: 447–465.

Sheffield EG and Hudson JA (2006) You must remember this: Effects of video and photograph reminders on 18-month-olds' event memory. *J. Cognit. Dev.* 7: 73–93.

Shuwairi SM and Johnson SP (2006) *Early Learning and Successful Object Tracking Through Occlusion: More Experience is Better.* Paper presented at the International Conference on Infant Studies, Kyoto, Japan, June 2006.

Simcock G and Hayne H (2002) Breaking the barrier? Children fail to translate their preverbal memories into language. *Psychol. Sci.* 13: 225–231.

Simcock G and Hayne H (2003) Age-related changes in verbal and nonverbal memory during early childhood. *Dev. Psychol.* 39: 805–814.

Spear NE and Parsons PJ (1976) Analysis of a reactivation treatment: Ontogenetic determinants of alleviated forgetting. In: Medin DL, Roberts WA, and Davis RT (eds.) *Processes of Animal Memory*, p. 135. Hillsdale, NJ: Erlbaum.

Squire LR (1987) *Memory and Brain*. Oxford: Oxford University Press.

Stevenson HW, Hess EH, and Rheingold HL (1967) *Early Behavior: Comparative and Developmental Approaches*. New York: Wiley.

Sweeney B and Rovee-Collier C (2001) The minimum duration of reactivation at 6 months: Latency of retrieval and reforgetting. *Infant Behav. Dev.* 24: 259–280.

Townsend D (2006) *The Transitivity of Preconditioned Infantile Associative Memories During Deferred Imitation.* PhD Thesis, Rutgers University, New Brunswick, NJ.

Tulving E (1983) *Elements of Episodic Memory*. Oxford: Oxford University Press.

Tulving E (1985) How many memory systems are there? *Am. Psychol.* 40: 385–398.

Tulving E and Thomson DM (1973) Encoding specificity and retrieval processes in episodic memory. *Psychol. Rev.* 80: 352–373.

Usher J and Neisser U (1993) Childhood amnesia and the beginnings of memory for four early life events. *J. Exp. Psychol. Gen.* 122: 155–165.

Vander Linde E, Morrongiello BA, and Rovee-Collier C (1985) Determinants of retention in 8-week-old infants. *Dev. Psychol.* 21: 601–613.

Wagner AR (1976) Priming in STM: An information-processing mechanism for self-generated or retrieval-generated depression in performance. In: Tighe TJ and Leaton RN (eds.) *Habituation: Perspectives from Child Development*

*Animal Behavior, and Neurophysiology*, pp. 95–128. Hillsdale, NJ: Erlbaum.
Watson JB (1930) *Behaviorism*. Chicago: University of Chicago Press.
Watson JB and Rayner R (1920) Conditioned emotional reactions. *J. Exp. Psychol.* 3: 1–14.
Watson JS (1984) Memory in learning: Analysis of three momentary reactions of infants. In: Kail R and Spear NE (eds.) *Comparative Perspectives on the Development of Memory*, pp. 159–179. Hillsdale, NJ: Erlbaum.
Wilk A, Klein L, and Rovee-Collier C (2001) Visual-preference and operant measures of infant memory. *Dev. Psychobiol.* 39: 301–312.
Willingham DB and Preuss L (1995) The death of implicit memory. *Psyche* 2: 1–10.

# 2.37 The Development of Skilled Remembering in Children

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## 2.37.1 The Development of Skilled Remembering in Children

A number of the intellectual giants of the nineteenth and early twentieth centuries thought seriously about the mnemonic abilities of young children. Initial considerations of children's remembering can be seen in Darwin's (1877) and Preyer's (1882/1889) diary case studies of their own children's memory skills, in Binet's (e.g., Binet and Henri, 1894a, Binet and Henri, 1894b) early experiments on children's memory for words and ideas, and in Freud's (1901) initial psychoanalytic writings about infantile amnesia. Sustained interest in children's memory was reflected in Hunter's (1913) basic studies of memory capacity and retention and in Stern and Stern's (1909) applied investigations of memory, suggestibility, and eyewitness testimony. Moreover, assessments of memory figured prominently in initial measures of intellectual capacity (e.g., Terman, 1916; Terman and

Merrill, 1937; Wechsler, 1939) – as they do today – but even this important early work did not prompt widespread interest in the development of memory. Indeed, reflecting to some extent the dominance of the behaviorist perspective in both experimental and developmental psychology, it would take more than 50 years for systematic research on children's memory to start to appear in the developmental literature. The first signs of renewed interest in the development of memory can be seen in Flavell's seminal explorations of children's use of strategies for remembering (e.g., Flavell, 1970; Flavell et al., 1996), and in a few years, there was sufficient critical mass in the area to justify a symposium on children's memory at the 1971 meeting of the Society for Research in Child Development. Flavell organized this now-celebrated symposium – "What is memory development the development of?" – to characterize what was then known about children's memory.

The last 35 years have witnessed a dramatic increase in research on children' abilities to remember (Kail and Hagen, 1977; Schneider and Pressley, 1997; Ornstein et al., 1998; Courage and Cowan, in press), but in many ways the research literature bears the imprint of the question posed at the 1971 symposium. Admittedly, the answers to this question have changed dramatically over the years as a function of changes in research paradigms, theoretical frameworks, and even the ages of the children being studied, but there has nonetheless been a consistent emphasis on characterizing that 'something' (e.g., strategies, underlying knowledge, basic capacity) thought to be changing with age (Ornstein and Haden, 2001; Ornstein et al., 2004). The net result is that a great deal is now known about the contrasting memory skills of children of different ages, as is documented in this chapter. However, in contrast to the progress that has been made in response to the 'what develops' question, relatively little is known about the process of development. For example, how do early manifestations of a skill (e.g., a naming strategy) give way to later and more sophisticated examples of that skill (e.g., a more complex rehearsal strategy), and what can be said about the rate of change that is observed? Most importantly, what factors are responsible for bringing about this developmental change? To a certain extent, researchers have focused remarkably well on issues of memory development but not very much on the development of memory (Ornstein and Haden, 2001; Ornstein et al., 2004).

In addition to this important distinction between memory development and the development of memory, the stage for this chapter is set by two pervasive themes in the now-voluminous research literature on children's remembering. First, a substantial corpus of work now documents the remarkable mnemonic competence of infants (e.g., Meltzoff, 1995; Rovee-Collier, 1995, Bauer et al., 2000; Bauer, 2006; *See* Chapter 2.36) and preschoolers (Baker-Ward et al., 1984; Goodman et al., 1990). Second, an equally impressive literature confirms the presence of substantial age differences in aspects of memory performance that include the degree of detail reflected in children's reports (e.g., Fivush and Hamond, 1990; Roebers and Schneider, 2001), the amount of forgetting observed (Brainerd et al., 1990; Howe and Courage, 1997), and the deployment and effectiveness of deliberate strategies for remembering (Ornstein et al., 1988; Bjorklund, 1990; Schlagmüller and Schneider, 2002). These two themes – the surprising competence of young children's memory on the one hand and clear age-related differences in performance on the other hand – represent a distillation of evidence stemming from research paradigms that range from elicited and deferred imitation (Meltzoff, 1995; Bauer et al., 2000, Bauer, 2006) and conditioning (Rovee-Collier and Shyi, 1992; Rovee-Collier, 1997) to those involving the production of narrative accounts of previous experiences (Fivush, 1991; McCabe and Peterson, 1991; Reese et al., 1993) and verbal measures of both strategy use and remembering (Baker-Ward et al., 1993; Folds et al., 1990; Schlagmüller and Schneider, 2002).

The aim of this chapter is to provide an overview of children's memory, focusing on age-related differences in the underlying processes of encoding, storage, retrieval, and reporting. With respect to the flow of information within the developing memory system, the emphasis is on early mnemonic competence and age-related changes in a range of memory skills, characterizing children's abilities at different points in time and exploring factors that serve to bring about change. However, reflecting the relative dearth of information in the literature on the development of memory, the bulk of the work reviewed here deals with memory development. To some extent, this state of affairs reflects the predominance of cross-sectional research designs, in which the performance of children of different ages is contrasted, and the infrequent use of longitudinal designs in which the same children are tracked over time. There are, of course, many reasons why cross-sectional designs have been favored, but longitudinal research is certainly necessary for an account of developmental change within individuals, especially given the evidence to date that cross-sectional findings are not always replicated within a longitudinal framework. For example, although the cross-sectional literature would suggest a smooth age-related progression in the skill with which an organizational strategy is deployed, inspection of individual developmental trajectories available from the Munich Longitudinal Study reveals a markedly different pattern: Children's strategic deployment seems to be characterized by inconsistency and abrupt change across measurement points (Sodian and Schneider, 1999). As such, longitudinal designs are essential if the aim is to address issues concerning the development of memory, but these designs must be chosen so as to provide information concerning factors – within the child and within the environment – that may serve as mediators of the developmental change that is observed.

The bulk of the chapter is devoted to characterizing age differences in various aspects of children's memory performance, making extensive use of the cross-sectional literature. To the degree possible, longitudinal data are utilized to supplement this characterization of children's abilities in an attempt to move the discussion to (1) a description of the course of developmental change and (2) a treatment of potential mediators of this change. However, because longitudinal research designs are inherently correlational in nature, the treatment of longitudinal studies is combined, where possible, with parallel experimental investigations in which hypothesized mediators of change (e.g., mother–child communicative interactions) are brought under experimental control. These experimental interventions (e.g., Carr et al., 1989; Boland et al., 2003) are necessary if the aim is to make causal statements about factors that serve to bring about developmental change. In addition, the findings of these cross-sectional, longitudinal, and intervention studies are supplemented by a discussion of the few extant microgenetic studies of children's memory. In microgenetic studies (see Siegler and Crowley, 1991; Siegler, 2006), frequent observations are made of children's performance during periods in which their skills are thought to undergo rapid change and development (e.g., Schlagmüller and Schneider, 2002).

The sections that follow are devoted to a discussion of two basic literatures that are not often treated together: Children's memory for specific events that are typically experienced without intent to remember, as well as their deliberate memory for materials that are encoded with the expectation of a subsequent memory assessment. These different aspects of mnemonic competence are discussed together because the underlying processes of encoding, storage, retrieval, and reporting seem to operate in a similar manner in each of these domains (Baker-Ward et al., 1997; Ornstein et al., 2006b). Moreover, it seems likely that elemental skills in talking about past experiences set the stage for later accomplishments within the domain of deliberate remembering (Haden et al., 2001). After a consideration of research on the nonverbal memory skills of infants and young toddlers, the discussion turns to children's verbally based memory for events and autobiographical experiences, and then to a treatment of their strategic efforts in tasks that require deliberate remembering.

## 2.37.2 Nonverbal Memory

Given its developmental focus, the emphasis in this chapter is on the emergence and growth of children's verbal mnemonic skills. Nonetheless, it is important to appreciate the fact that the verbal skills that are described here are built upon a nonverbal foundation and that considerable attention has focused on characterizing this foundation (see, e.g., Barr and Hayne, 2000; Rovee-Collier et al., 2001; Bauer, 2006; Oakes and Bauer, 2007; Courage and Cowan, in press), with researchers using a wide variety of behavioral measures to piece together a picture of what infants can remember over varying delay intervals. Two caveats are in order, however, as we begin this brief treatment of early memory. First, the conclusions that one can reach about young children's memory seem to vary as a function of the measures used to assess remembering, and little is known about the extent to which the different measures converge to characterize children's skill at any one point in development. Second, little is also known about the ways in which children's nonverbal memory performance leads to (or predicts) subsequent performance on tasks that require verbal reports.

### 2.37.2.1 Estimates of Long-Term Retention

It is clear that infants evidence remarkable skills in being able to retain information over delays that increase dramatically over the first year and a half of life. Early retention has been demonstrated in paradigms ranging from visual paired comparison and habituation to conditioning and imitation, with estimates of retention in neonates that range from a few minutes to weeks on visual habituation tasks (e.g., Slater et al., 1984; Pascalis et al., 1998), to months by the end of the first year on elicited imitation tasks (e.g., Carver and Bauer, 2001). But what can be said about the age-related changes in the nature and complexity of the information that is being retained? To illustrate current understanding related to this important question concerning early memory, we focus on studies of children's performance in the context of two tasks: operant conditioning (*See* Chapter 2.36) and elicited/deferred imitation procedures. (Meltzoff, 1985, 1995; Bauer, 2007). Systematic research with these behavioral tasks has enabled researchers to document infants' quite dramatic mnemonic skills and has also sparked a lively debate concerning the nature of early memory (e.g. Nelson, 1995; Bauer, 1996; Rovee-Collier, 1997).

#### 2.37.2.1.1 Conjugate reinforcement paradigms

In the conjugate reinforcement paradigm, an infant – typically between 3 and 6 months of age – is placed on her back with a mobile overhead. After an operant period in which the infant's base level of kicking is measured, her leg is connected via a ribbon to the mobile. With this arrangement, each kick is followed by the reinforcement of observing the mobile move, and stable responding in its presence can easily be established. With the operant response acquired, remembering after varying intervals can readily be assessed under conditions of extinction in which the ribbon is disconnected from the mobile, so that no contingencies are in effect. Memory is then inferred if the rate of kicking observed in these test periods is greater than that seen in the baseline period, and under these conditions two fundamental patterns of age differences in performance in the first 6 months of life have been reported: Both speed of learning and length of retention increase with age. Thus, older infants acquire the kicking response more rapidly than younger children, and when trained to the same criterion of performance, they retain it longer than their younger peers (e.g., Hill et al., 1988).

Programmatic research with the mobile conjugate reinforcement task has also revealed two other important features of early memory. First, under some conditions, memories that would seem to be forgotten can be cued and recovered. Indeed, by using reinstatement, partial reminders of a previous experience (Campbell and Jaynes, 1966), and reactivation (Spear and Parsons, 1976) procedures in which a component of the original event is presented at the end of the delay interval, retention of the kicking response can be extended considerably (e.g., Sweeney and Rovee-Collier, 2001). Typically, exposure to the mobile or the context (e.g., the crib lining) can serve to maintain memory over an extended delay, but the timing of the reminder is of critical importance, with maximal facilitation occurring if it is administered shortly before the assessment of long-term memory, as long as the response has not yet been forgotten (Sullivan, 1982; Rovee-Collier et al., 1987; Rovee-Collier and Hayne, 1987). Second, Rovee-Collier and her colleagues have shown that the kicking response can be remarkably sensitive to changes in aspects of the mobile and/or the context, with maintenance of responding being dependent upon a complete overlap in the cues present during learning and subsequent testing. Even a change in a single element of the mobile or the decoration on the crib liner can lead to dramatic disruptions in performance (Hayne et al., 1986; Borovsky and Rovee-Collier, 1990; Rovee-Collier et al., 1992). These findings provide useful information about the precision of early memory and the specificity of the underlying representations in memory that have been established (*See* Chapter 2.36).

#### 2.37.2.1.2 Imitation-based paradigms

In the elicited and deferred imitation paradigms, memory is demonstrated when an infant is able to use props to reproduce an action sequence that had previously been modeled by an examiner. Consider, for example, the acts involved in constructing a gong: putting a crossbar atop two posts, hanging a metal plate on the crossbar, and then hitting the plate with a plastic mallet. After a baseline period in which a young child interacts freely with these materials, an experimenter demonstrates the sequence that will lead to the construction of the gong one or two times while, under some conditions, providing simple labels for each of the actions. Typically, in the elicited but not the deferred imitation procedure, the modeling of these actions is accompanied by a verbal description of the target actions and the goal of the event sequence. Moreover, in the elicited imitation paradigm, an immediate assessment of memory is typically obtained, with the child being invited to imitate the modeled sequence of actions: for example, "Now you show me how to make a gong." Memory is usually also assessed after a delay, with and without the verbal cue. In contrast, in the deferred paradigm, imitation is assessed, but without much verbal prompting, and only following a delay. As such, in the deferred imitation procedure, there is no immediate indication of remembering – and hence of initial encoding, or even of whether the child has the motor ability to reproduce the sequence – although control groups have been used to approximate children's ability to imitate the sequences following presentation (see Meltzoff, 1985; Barr et al., 1996). In tests of elicited imitation, children act as their own controls, such that memory is indexed by their better performance with previously modeled versus novel event sequences. It is worth noting that the procedural differences between the deferred imitation and elicited imitation tasks can make a difference in memory performance (e.g., Hayne et al., 2003), with exposure to language cues and the opportunity to imitate the action sequences immediately after modeling facilitating long-term retention.

As previously mentioned, converging evidence from the elicited and deferred imitation paradigms shows that the age-related changes that begin in infancy, to the extent to which information can be held in memory, continue during toddlerhood. For example, 6-month-olds are able to produce parts of a three-step sequence 1 day – but not 2 days – after it is modeled (Barr et al., 1996). Importantly, two features of this demonstration of early recall provide a foundation from which improvement in mnemonic skill can be observed across the first 2 years of life. First, recall at 24 h is dependent upon the amount of experience that the infants have with the modeled action sequence: Approximately two-thirds of the children who had seen the three-step sequence six times produced at least one of the actions 1 day later, whereas the children who had observed the sequence only three times did not differ from control participants who had not witnessed the modeling. Second, there is essentially no evidence that the children can produce the components of the sequence in order, either immediately or after the 24-h delay. In contrast, by 9 months of age, infants are able to recall individual components of novel two-step sequences after 5 weeks (Carver and Bauer, 2001). Approximately half of the 9-month-olds are able to produce the sequences in correct temporal order after a delay of 5 weeks (e.g., Bauer et al., 2003) but not after 3 months. To be sure, this is a period in which skills for remembering change in a dramatic fashion, as illustrated by the fact that by 10 months, children evidence ordered recall at delays of both 1 and 3 months (Carver and Bauer, 2001).

Although this improvement in performance is certainly impressive, it should nonetheless be emphasized that the temporally ordered recall of 9- and 10-month-olds is still rather limited. First, the children's recall is dependent upon multiple exposures to each modeled event sequence. Indeed, as Bauer (2006) indicates, ordered recall at these ages is observed if the infants observe the target sequence on two (and sometimes three) occasions before the onset of the delay. Under these conditions, approximately 45% of the infants evidence ordered recall after 1 month; however, if children view a to-be-remembered sequence at only one session, then these figures drop considerably, with only 7% providing ordered recall (Bauer et al., 2001; Bauer, 2006). Second, the size of the event sequences that are to be remembered is rather small, with 9- and 10-month-olds typically being able to remember two-step events, and third, the length of time over which information can be remembered is quite short.

Each of these limitations is overcome to a considerable extent over the course of the second year of life. For example, by 13 months of age, children no longer need multiple exposures to an event in order to remember it over a delay of several months (Bauer et al., 1995), and yet remembering is clearly enhanced by the opportunity to experience an event sequence several times. In addition, with increases in age, children are better able to remember longer sequences for greater periods of time. To illustrate, in contrast to the two-step events that are remembered by 9- and 10-month-olds, children at 24 months of age can produce sequences of five steps in length (Bauer and Travis, 1993). Finally, the length of time across which ordered recall can be observed increases dramatically during this time period; indeed, 100% of children at 20 months of age are able to recall in an ordered fashion after 1 month, with more than half evidencing memory for portions of the to-be-remembered sequences after delays as long as 1 year (Bauer et al., 2000). For additional information concerning imitation-based approaches to the exploration of young children's memory, see Bauer's recent reviews (2006, 2007).

### 2.37.2.2 Exploring the Underlying Representation

Research on young children's memory with the conjugate reinforcement and imitation-type paradigms provides information about age-related differences in the conditions under which representations in memory can be established and maintained over time. But what can children's behavior in these two types of situations tell us about the structure and contents of these representations? The conjugate reinforcement procedure is a recognition (as opposed to recall)-based assessment, in which the index of remembering is based on kicking in the presence of a previously experienced stimulus. The specificity of children's responding in these studies – with the response rate dropping off markedly as a function of changes in the mobile or crib context – would suggest that the representation is both detailed and specific. However, even though variation in kicking patterns provides a sensitive indicator of whether or not elements of the mobile or context have changed, the procedure is not informative about the ways in which component features may be organized sequentially in the underlying representation. Yet this type of information is available in the imitation paradigms because responding involves recall, albeit action-based – not verbally based – recall, as opposed to recognition. Admittedly, infants cannot generate long strings of actions, but those that they do produce include the elements of events that are being remembered. Moreover, with increases in age, children's productions become more and more sequentially organized, thus reflecting the structure of the events and the underlying organization of the representation (Bauer et al., 2000). Finally, 1- to 2-year-olds readily apply their prior knowledge to the task of remembering action sequences, as can be seen in their enhanced recall of enabling as opposed to arbitrary sequences (Bauer et al., 2000). With enabling sequences, each action must be performed in a temporally invariant pattern in order to reach the end state (e.g., making a rattle with a ball and a nesting cup by first placing the ball in one-half of the cup and then covering it with the other half before it is shaken); in contrast, in arbitrarily ordered sequences, there are no inherent constraints on the temporal position of the actions (e.g., in making a party hat, it does not matter if a pompom is put on top before a sticker is placed on the front).

### 2.37.2.3 Bridges to Verbally Based Remembering

Researchers using conjugate reinforcement and imitation-based tasks have provided alternative perspectives on the mnemonic skills of infants, but it is nonetheless clear that these views are complementary and indicate that an impressive memory system is in place before language is available for the encoding and reporting of information. Given these demonstrations of a mnemonic foundation, what can be said about linkages between early nonverbal memory and later verbally based skills for remembering information? At one level, statements about the extent to which young children's early (and rapidly changing) abilities are related to their later verbally based mnemonic skills are quite limited. These statements must be based on longitudinal studies in which children are assessed initially on nonverbal memory tasks and then later on verbally based procedures, and the necessary data have not yet been reported in the literature. At another level, however, questions about linkages between early nonverbal and later verbal memory can be addressed in terms of the types of memory systems that are in place at the two points in time, and from this systems perspective, there may indeed be evidence for developmental continuity. More specifically, a strong claim can be made that the imitation-based tasks tap explicit (as opposed to implicit) memory, and thus line up well with the explicit memory tasks that are employed in assessments of children's abilities to talk about past experiences and prepare for deliberate assessments of memory (Bauer, 1996, 2006).

In order to evaluate this claim, it is necessary to review the distinction between explicit and implicit memory. There certainly are many ways of characterizing memory, but a distinction between explicit (or declarative) and implicit (or nondeclarative) memory is widely accepted (Schacter, 1987; Squire, 1987; Moscovitch, 2000). These two types of memory are thought to differ on many dimensions. For example, in the type of information that is being remembered, in the speed with which it is acquired and lost over time, and in the degree to which remembering involves conscious recollection. To illustrate (and greatly simplify), consider the way in which an experience of visiting a friend may be processed by the explicit memory system. The features of this visit (e.g., names, facts, locations) are rapidly encoded, but specific information can also be lost over time (and/or replaced in a constructive manner with related information). Yet, in any event, the telling of the tale certainly involves conscious recollection. Now, by way of contrast, consider the way in which a perceptual motor skill – such as driving a car or riding a bicycle – is acquired and represented in implicit memory. These skills require a great deal of practice and are literally honed over longer periods of time; but once mastered, there is little forgetting, and production does not entail conscious recollection. In addition, recent research suggests that in the latter half of the first year, it is possible to differentiate explicit and implicit memory systems structurally, with explicit memory relying on the hippocampus (in particular, the dentate gyrus and other supportive cortical structures), and implicit memory depending on the neostriatum and cerebellum (Eichenbaum, 2003).

From this vantage point, the types of memory that are the focus of this chapter – e.g., a child's report of a recently experienced event or recall of a list of words – would certainly be seen as involving the explicit memory system, but what can be said of the demonstrations of children's nonverbal memory prowess discussed above? To the extent to which any one of the nonverbal tasks used to assess memory in infancy can be viewed as tapping into the explicit memory system, there would be continuity across the nonverbal/verbal divide in terms of memory systems that are in place. In this regard, Bauer (2006, 2007) has argued convincingly that the imitation-based techniques capture the essence of explicit memory. She points out that the infants who are assessed with imitation-based procedures rapidly encode and learn the modeled event sequences, without extensive practice, but also that their memories are fallible, with considerable forgetting over time being observed. Moreover, the memory that is assessed with imitation procedures is clearly rather flexible in that it is preserved (or generalized) across variations in materials contexts. Admittedly, these tasks do not involve verbal reports, and it is impossible to know whether the infants whose performance is assessed experience a sense of conscious recollection, but one other source of evidence is relevant to the argument: Adult humans with amnesia that impairs their performance on explicit memory tasks have been shown to have deficits on the elicited imitation task (McDonough et al., 1995).

In contrast to these procedures, conjugate reinforcement has typically been viewed as reflecting implicit memory (Mandler, 1990, 1998; Schneider and Bjorklund, 1998; but see Rovee-Collier, 1997, and Chapter 2.36, for a contrasting perspective). As indicated in Section 2.37.2.1.1, these tasks are based on operant conditioning procedures, and both operant and classical conditioning have been taken – along with perceptual-motor skills and priming – to be indicators of implicit, as opposed to explicit, memory. Moreover, the contrast between conjugate mobile and imitation tasks can be seen in the basic features of performance: Learning in the conjugate reinforcement task takes a considerable amount of practice before stable levels of kicking are reached, and once the response is acquired, the memory seems to exhibit very high levels of specificity. Indeed, as suggested earlier, even minor changes in the mobile or the context are sufficient to disrupt performance considerably.

Given this view that deferred and elicited imitation tasks involve the same explicit memory system that is activated in verbally based tasks, we would expect that longitudinal analyses would reveal linkages between children's performance on the different procedures. Another reason for this expectation is that the imitation tasks seem to have greater face validity than does conjugate reinforcement, especially in terms of potential links both to language and to event memory as is reflected in assessments of older children's mnemonic skills. For example, although the evidence is admittedly mixed (Bauer et al., 2000; Bauer, 2006), under some conditions young children's elicited imitation is influenced positively by their language skills, and it is known that verbal ability plays a significant role in later events and autobiographical memory (Bauer and Wewerka, 1995; Welch-Ross, 1997; Boland et al., 2003). In addition, the task demands of the elicited imitation procedure seem similar in certain critical respects to those of tasks that are used to explore 2- and 3-year-olds' reports of their previous experiences. More specifically, the conversations between young children and their parents about recently experienced events that will be discussed below involve remembering and subsequently reporting the details of these experiences. As such, both elicited imitation and mother–child reminiscing procedures involve event recall, even though remembering is expressed motorically in one procedure and verbally in the other. Moreover, given that both procedures yield information about children's recollections about the component details of previously experienced events, they, in principle, provide insight into the underlying memory representations.

Given this discussion of conceptual linkages between the elicited imitation and verbally based assessments of children's memory, we turn now to a treatment of children's verbal reports of personally experienced events. In the section that follows, we provide an overview of children's memory for routine and unique experiences and discuss factors that impact developmental changes in remembering.

## 2.37.3 Learning to Remember

### 2.37.3.1 Remembering Previously Experienced Events

Starting with the work of Nelson and her colleagues (e.g., Nelson and Gruendel, 1979; see Nelson, 1986, for an overview) on children's memories for familiar and recurring events, the corpus of research on preschool-aged children's abilities to remember their personal experiences has expanded in an impressive fashion. Indeed, in addition to what we now know about children's abilities to produce scripts or generalized event representations for routine experiences such as going grocery shopping or dining at a restaurant, there is now a voluminous literature concerning their abilities to recall the details of specific, distinctive events that they have experienced. In providing a selective treatment of this work, we first discuss research on children's scripts, then review evidence concerning their memory for salient target events, and finally move to a description of studies that have emphasized event memories expressed in parent–child conversations about the past. We do so with a focus on the establishment, maintenance, and modification of event memories, emphasizing the role that knowledge plays in affecting the flow of information through the developing memory system.

#### *2.37.3.1.1 Children's scripts*

In their initial studies, Nelson and Gruendel (1981) conducted semistructured interviews with children as young as 3 years of age about what happens during familiar and routine events, such as eating at McDonald's, making cookies, and attending a birthday party. The results of these and later studies (Nelson, 1978; Nelson and Gruendel, 1979; Nelson et al., 1983; Fivush, 1984; Fivush and Slackman, 1986) demonstrate that preschoolers are able to give both veridical and consistent reports of what typically occurs during such events, although certainly older children's scripts are more detailed than those of younger children. Moreover, these script reports reflect the ways in which the events being described are structured in the world, just as the elicited imitation performance of infants studied by Bauer reflected the organization of the action sequences being remembered. To illustrate, in both settings some events are ordered in an enabling fashion, such that each component activity sets the stage for the next activity, whereas other components are arbitrary and variable in their temporal order. For example, in going to McDonald's, one must order food before one can eat it, whereas during a birthday celebration, one must open presents, but this does not have to happen at any particular time during the event. Children as young as 3 years of age are sensitive to these distinctions, recounting activities connected by enabling relations in their experienced order, whereas arbitrary activities are recalled in variable order (see, e.g., Fivush et al., 1992). Equally intriguing, children recount more information about events that are linked by enabling relations than those that are arbitrarily ordered, with some suggestion that this may be true even after the very first experience with the events (Slackman and Nelson, 1984; Ratner et al., 1990; Fivush et al., 1992; Murachver et al., 1996). The linkages between Bauer's elicited imitation studies and this research on verbal scripts lead to the basic conclusion that as early as 12 months of age, children are sensitive to the structure of events in the world, and that their memory reports of those events reflect this structure.

#### *2.37.3.1.2 Memory for salient events*

Supplementing research on children's generic representations of recurring events is a considerable body of work on young children's memory for unique personally experienced events. In some studies, children have been exposed to a range of specially crafted stimulus events, such as visiting a pirate (Murachver et al., 1996) or a pretend zoo (McGuigan and Salmon, 2004), whereas in others, the focus has been on naturally occurring routine visits to the doctor and other less familiar and more stressful medical experiences (Merritt et al., 1994; Peterson and Bell, 1996; Goodman et al., 1997; Ornstein et al., 1997a; Burgwyn-Bailes et al., 2001). This literature indicates the presence of substantial age differences in various aspects of memory performance. To illustrate, with increases in age, children demonstrate higher levels of overall recall of these experiences, recount more information in response to open-ended questions, and thus show less dependence on yes/no questions to elicit memory (e.g., Fivush and Hammond, 1990; Baker-Ward et al., 1993; Ornstein et al., 1997). Moreover, older children evidence less forgetting over time (Brainerd et al., 1985, 1990; Ornstein, 1995) and are less susceptible to suggestive questions (Ceci and Bruck, 1995; Ornstein et al., 1997). Existing evidence also indicates that with age and increased experience in talking about the past, children's reports become more richly detailed and complex and less dependent on information being provided by adult conversational partners (e.g., Fivush et al., 1995; Haden et al., 1997).

In one illustration of this work, Baker-Ward et al. (1993) assessed 3-, 5-, and 7-year-olds' memory for details of a routine pediatric examination. Most children were interviewed two times, first immediately after the check-up and then after a delay of 1, 3, or 6 weeks. The interviews were structured in such a way that they began with open-ended questions (e.g., "Tell me about what happened during your check-up."), followed by more specific questions (e.g., "Did the doctor check any parts of your face?"), and, finally, yes/no probes (e.g., "Did she (he) check your eyes?"). The children were asked yes/no questions both about features that had not been volunteered in response to the open-ended probes as well as regarding activities that had not been included in the check-ups. As illustrated in the top panel (A) in **Figure 1**, even the 3-year-olds were able to report most (approximately 75%) of the features of the event. However, as illustrated in the lower panel (C) in **Figure 1**, there were clear age-related improvements in performance, such that the 7-year-olds reported the greatest number of features (approximately 90%). Moreover, even though the performance of the 3-year-olds was impressive, they nonetheless produced less information than the older children in response to open-ended probes – as shown in the black portion of the bars in the figure – and thus required more specific questions to provide information about the experience. A comparison of the bars across the three panels at each delay reveals that the younger children evidenced more forgetting than the older children over the 6 weeks of the study.

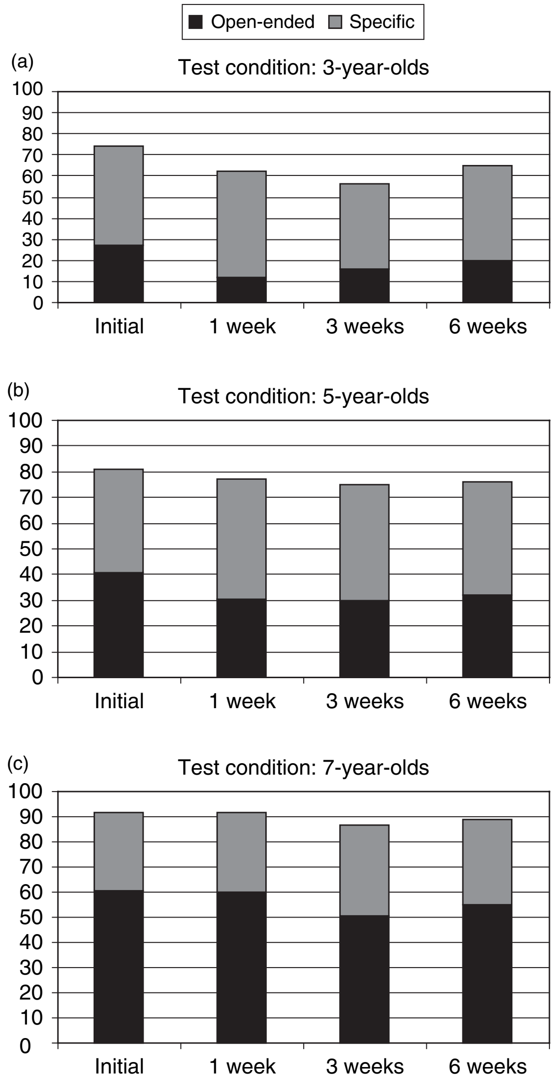


**Figure 1** Percent of features correctly reported in response to open-ended and specific probes by test condition at ages 3 (panel A), 5 (panel B), and 7 (panel C) years. Note that the data presented for the initial test are averaged across the three delay groups. Adapted from Baker-Ward L, Gordon BN, Ornstein PA, Larus DM, and Clubb P (1993) Young children's long-term retention of a pediatric examination. *Child Dev.* 64: 1519–1533. Copyright © 1993, Blackwell.

## 2.37.3.2 The Role of Knowledge

The event memory literature has both challenged earlier views of young children's recall as being quite limited (e.g., Myers and Perlmutter, 1978) and raised important questions about how we are to understand the dramatic age-related changes in remembering in terms of the factors that contribute to the encoding, storage, retrieval, and reporting of information. Children's understanding of the events being experienced is one such factor, as age differences in knowledge can seriously affect the processing and retention of information in memory.

#### 2.37.3.2.1 Prior knowledge

It is well known that prior knowledge enables people to create initial expectations that serve to focus their attention and make inferences that facilitate comprehension, so as to influence what gets into memory (Bjorklund, 1985; Chi and Ceci, 1987; Ornstein et al., 1997). In general, events about which children have significant prior knowledge are more readily encoded and subsequently retrieved than are those about which they have less knowledge. For example, studies that focus on the development of expertise in specific domains (e.g., chess, soccer) have demonstrated repeatedly that the highly organized and accessible knowledge of experts enables them to encode and remember domain-relevant information more effectively than novices (e.g., Chi, 1978; Schneider et al., 1989). In a similar manner, children's scripts (Nelson, 1986) that reflect their understanding of frequently occurring events can markedly affect their later memory of specific instances of these experiences (e.g., Farrar and Goodman, 1990).

An illustration of the impact of prior knowledge on memory can be seen in a reanalysis of the 5-year-olds' recall data from the Baker-Ward et al. (1993) study that was discussed in section 2.37.3.1.2. Clubb et al. (1993) rescored the protocols from the Baker-Ward et al. study to create memory scores representing the proportion of children who recalled each component of the check-up (e.g., blood pressure, eye check, urine specimen) in response to open-ended questions. These memory scores for each component of the office visit at each recall assessment were compared to knowledge scores that were constructed on the basis of interviews with a separate sample of 5-year-olds who responded to questions about what generally happens when they go to the doctor (e.g., "What does the doctor (nurse) do to check you?"). The knowledge scores were therefore based on the proportion of children in the Clubb et al. (1993) sample who nominated each component of the check-up in response to the interviewers' general knowledge probes. Given comparable memory and knowledge scores for individual features of the pediatric check-up, it was possible to determine the degree to which the recall of the 5-year-olds in the Baker-Ward et al. (1993) study could be predicted on the basis of Clubb et al.'s (1993) normative knowledge data.

Inspection of the data plotted in **Figure 2** indicates that there was considerable variability in the memorability of the components of the physical

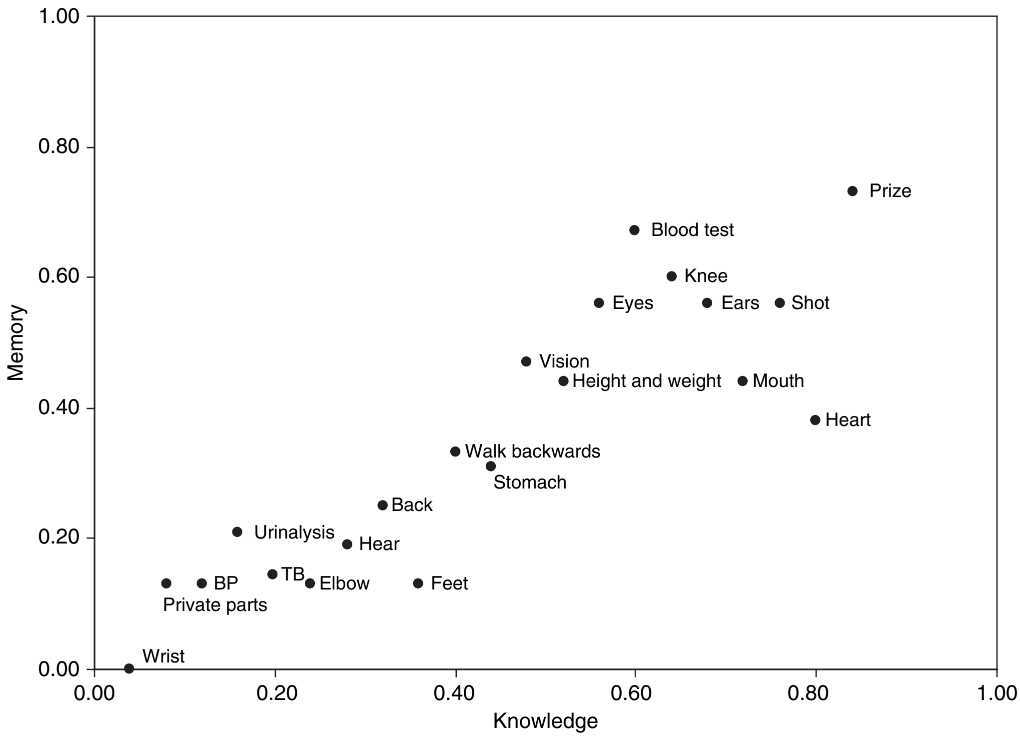


**Figure 2** Scatterplot of knowledge and memory scores at 6 weeks for 5-year-olds. Reprinted with permission from Clubb PA, Nida RE, Merritt K, and Ornstein PA (1993) Visiting the doctor: Children's knowledge and memory. *Cogn. Dev.* 8: 361–372. 

examination. There was also variability in the children's knowledge of the individual features, but most interestingly, the knowledge and memory scores were highly correlated, indicating that increases in knowledge were associated with corresponding increases in remembering; indeed, the correlations were 0.68, 0.63, 0.64, and 0.74 for the initial, 1-, 3-, and 6-week (shown in **Figure 2**) interviews. These data (see also Ornstein et al., 1997b) and other findings with the subject as opposed to the feature as the unit of analysis (Ornstein et al., 2006a) strongly suggest that what a child knows about an event can seriously affect the extent to which information about the experience is coded and placed in memory.

Although prior knowledge certainly impacts children's memory performance positively, it is important to note that it also can have negative effects. To illustrate, in an effort to explore the extent to which an individual's general knowledge can, over time, lead to alterations in memory for a specific event, Ornstein et al. (1998) studied 4- and 6-year-olds' long-term memory for the details of a specifically constructed physical examination that was both consistent and inconsistent with knowledge-driven expectations. In this experiment, the stimulus event was a mock physical examination carried out by a licensed pediatrician that included some typical medical features (e.g., listening to the heart with a stethoscope) but omitted others that, on the basis of prior knowledge, would have been expected to occur (e.g., checking the mouth). These omitted features, moreover, were replaced by unexpected and quite atypical medical procedures (e.g., measuring head circumference). The findings indicated that prior knowledge had both positive and negative effects on performance. Expected features of the procedures were better remembered than atypical features at all assessments. Most interestingly, 12 weeks after their check-ups, the children made spontaneous errors of commission (i.e., they claimed that they experienced certain medical procedures that had not been administered) and evidenced high rates of false alarms to yes/no questions about medical features that had not been included in their check-ups. The spontaneous intrusions of omitted-but-expected features and the low rates of correct denials to explicit questions about these features that were observed by Ornstein and his colleagues are consistent with the view that the representations of the children's check-ups changed over the 12-week delay interval. More specifically, it would seem that as the children's memory for the check-ups faded over the course of the interval, aspects of their generic event representations for visits to the doctor were incorporated into their specific event representations.

#### *2.37.3.2.2 Knowledge that is acquired during an event*

When previously acquired knowledge is lacking, as in a situation in which a child experiences a novel event, facilitative effects can be observed when knowledge is gained while the experience is taking place. For example, Principe et al. (1996) used data from a study of 3- to 7-year-olds' memory for an invasive and novel radiological procedure (a voiding cystourethrogram, or VCUG; Merritt et al. 1994), to look at how the provision of information to children during the event about the stressful and unfamiliar medical procedure affected their subsequent remembering of the experience. Interestingly, the radiological technicians involved in the procedure naturally varied in the extent to which they provided medically relevant information to the children about the experience as it was ongoing. Therefore, whereas some children were provided with a verbal description of the catheter and its insertion, some mention of the contrast fluid going through the catheter, and information about the filling of the child's bladder with this fluid, other children did not receive this procedural narrative. Underscoring the dramatic impact of new knowledge on comprehension and memory, children in the procedural narrative group remembered more details immediately after the exam, as well as 6 weeks later, than children who were not given such a description. These differences could not be attributed to differences among the children in their age or their levels of stress during the procedure and suggest that information that is gained during an unfamiliar and stressful event enhances remembering.

#### *2.37.3.2.3 Changes in knowledge*

Once in the memory system, the status of information about an experience can be substantially altered during the period between the event and the later report of it. Indeed, a number of variables can contribute to changes in the representation, including the passage of time (Ornstein et al., 2006a) and intervening experiences (Principe et al., 2000), and these influences may vary as a function of age. Moreover, because knowledge does not remain constant over time, it is important to ask what happens when knowledge itself changes. Ross (1989) has argued cogently that as memory for the details of an experience fades over time, one tends to 'fill in' on the basis of current understanding and knowledge. One demonstration of the ways in which changes in knowledge over time can lead to alterations in remembering was reported by Greenhoot (2000), who used a series of stories as stimulus material to lead children to develop certain assumptions about the protagonists. Over the course of several sessions, the 5- and 6-year-olds who participated in her study built up a knowledge base about the main story characters and their relationships, and hence the underlying motivation for certain acts that were depicted in the stories. Then, at later sessions, the children were given additional information that prompted some of them to reassess the relationships among the characters (and the motivation for various behaviors) that had been operative. Importantly, Greenhoot showed that the children's memory for prior episodes was distorted in the direction of the new information.

#### *2.37.3.2.4 Recall in conversations about past events*

Although much has been learned about children's memory for salient events, a great deal needs to be done to understand how a variety of factors come to together to influence the establishment, maintenance, and modification of representations in memory. In this regard, it is clear that adults have a great role to play in facilitating children's understanding and remembering. Indeed, social–communicative interactions between parents and children provide opportunities for focusing children's attention on salient aspects of an event and thus increasing their understanding and memory, as well as facilitating the acquisition of generalized skills for remembering.

#### *2.37.3.2.5 Parental reminiscing styles*

Children begin to talk about past events almost as soon as they produce their first words, and the skills for recalling past experiences in parent–child conversations develop rapidly between 2 and 4 years of age. Nevertheless, as illustrated in this example of a mother and her 18-month-old, when children first begin to reminisce, it is the adult partner who provides most of the content and structure.

> Mother: What else happened [at Taylor's house]?
> Child: (no response)
> Mother: We had dinner. What did you eat?
> Child: (goes off task).
> Mother: What did you do with Taylor?
> Child: Barney.
> Mother: Yeah, you watched a Barney video. What else did you do with Taylor? Did you guys fight about something?
> Child: (shakes head no).
> Mother: No? When you were watching Barney?
> Child: (nods head yes).
> Mother: Yeah. You guys got hungry and tired. Then what happened?
> Child: Uh oh.
> Mother: Yeah. What happened? Did you bite Taylor's finger?

A central focus in the literature on parent–child reminiscing has been on the marked individual differences in the reminiscing styles parents use to structure conversations about the past with their young children (see Fivush et al., 2006, for a review). In contrast to parents who use a low elaborative style, those who employ a high elaborative style – such as the mother in the example above – ask many questions, follow-in on their children's efforts to contribute to the conversation, and continue to add new information even when children do not. It is clear that these reminiscing styles generalize across different types of past event discussions (e.g., excursions and holidays, zoo or museum trips, entertainment outings) and tend to be consistent over several years with the same children (Reese et al., 1993) and across different-aged children in the same family (Haden, 1998). Most important, longitudinal data indicate that differences in maternal reminiscing styles are associated with later differences in children's abilities to recall personally experienced events. For example, as illustrated by the lagged correlations in **Figure 3**, Reese et al. (1993) demonstrated that mothers' elaborations during conversations with their 40-month-old children are associated positively with children's contributions of memory information in conversations with their mothers at 58 and 70 months of age. Moreover, the direction of the effect was more from mother to child over time than from child to mother. Although children did influence their mothers to a limited extent, as illustrated in the lower portion of the figure, the correlations for memory responses across age indicate that the children's own earlier skills for verbally recalling events were not directly related to their later abilities.

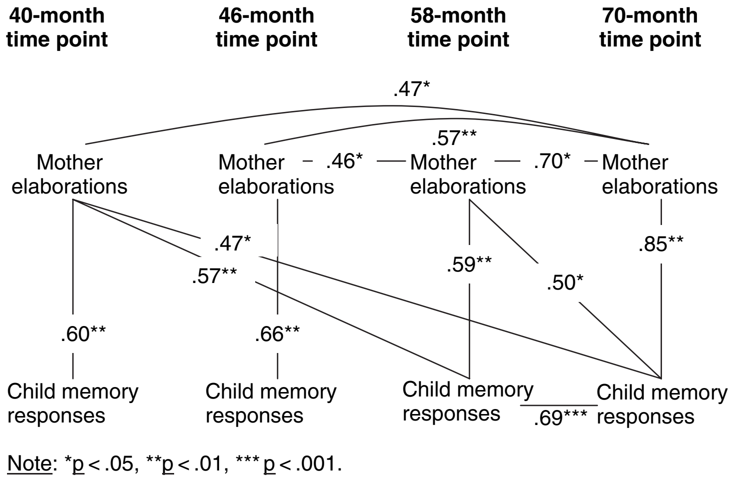


**Figure 3** Cross-lagged correlations between maternal elaborations and children's memory responses. Reprinted with permission from Reese E, Haden CA, and Fivush R (1993) Mother-child conversations about the past: Relationships of style and memory over time. *Cogn. Dev.* 8: 403–430. Copyright © 1993, Elsevier.

The finding that the more mothers engaged in highly elaborative talk about the past, the better their children's event memory skills even years later, has been widely replicated both in the United States and cross-nationally (e.g., Hudson, 1990; Flannagan et al., 1995; Welch-Ross, 1997; Haden, 1998; Harley and Reese, 1999; Peterson et al., 1999; Farrant and Reese, 2000; Leichtman et al., 2000; Low and Durkin, 2001; Welch-Ross, 2001; Fivush and Vasudeva, 2002; Bauer and Burch, 2004), such that it seems clear that mothers who are highly elaborative early in development facilitate their children's abilities to report on their past experiences in a detailed manner. Moreover, Peterson et al. (1999) were successful in manipulating mothers' conversational style when talking with their children about previously experienced events, finding that children of mothers who received their intervention produced longer memory reports that contained more details about past events than children of mothers who had not received reminiscing training.

Findings concerning the impact of maternal reminiscing styles on remembering have led to speculation about how early conversations about the past may change the way children organize and represent experiences (Fivush and Haden, 1997; Fivush et al., 2006). Interestingly, it has been suggested that children of mothers who use a highly elaborative reminiscing style may actually come to encode experiences in more richly detailed ways than children of less elaborative mothers, although presently no study has addressed this particular issue. Nevertheless, just as memories may be maintained, elaborated, or even modified through subsequent reminiscing, a growing body of evidence supports the idea that language-based interactions during events can be of critical importance in guiding initial encoding and the establishment of a representation in memory (Tessler and Nelson, 1994; Haden et al., 2001; Boland et al., 2003; McGuigan and Salmon, 2004; Ornstein et al., 2004; Hedrick, 2006). It is to this work that we now turn.

#### *2.37.3.2.6 Conversation during events*

The few studies to date that have examined mother–child talk during an event suggest that preschoolers produce longer and more detailed reports of these experiences if their mothers use elaborative Wh-questions and follow-in on and positively evaluate their children's verbal and nonverbal behaviors as events unfold (Haden et al., 2001; Boland et al., 2003; Ornstein et al., 2004). Moreover, joint linguistic interactions between parents and children during events are more strongly related to children's later memory than are interactions characterized as primarily involving mother-only talk, child-only talk, or no-talk (Tessler and Nelson, 1994; Haden et al., 2001). To illustrate, Haden et al. (2001) conducted a longitudinal investigation in which young children took part in three specially constructed activities with their mothers: At 30 months, a camping trip; at 36 months, a bird-watching adventure; at 42 months, the opening of an ice-cream shop. Within the confines of each family's living room, mother–child interactions during the events were videotaped, providing a precise record of how each dyad interacted – both nonverbally and verbally – with each component feature of the event (e.g., in the camping event, hot dogs, marshmallows, backpack, sleeping bag) as it unfolded.

Given that the majority of features that were interacted with during the events were jointly handled (and thus jointly attended to), Haden et al. (2001) asked whether recall of these components varied as a function of the type of talk (e.g., joint verbal, mother-only verbal, child-only verbal, no verbal) that had been directed toward them during the activities. The children's recall of these experiences after delays of 1 day (upper panel) and 3 weeks (lower panel) is summarized in **Figure 4**. Inspection of the figure indicates the striking effect of joint talk as the events unfolded on the information the children provided in response to the open-ended questions of the interviewers. As can be seen, at both interviews and for each of the activities, the features that were handled and discussed by both the mother and the child jointly (solid bars) were better recalled than those that were jointly handled but talked about only by the mother (gray bars), which, in turn, were better recalled than those not discussed (white bars). Additional analyses indicated further that the features of the event (e.g., a spatula in the camping event) about which questions had been asked by the mothers during the activity that had been responded to by the children (e.g., the mother asks, "What is the spatula used for?" and the child responds "For flipping.") were better recalled than features about which mothers' questions did not result in the children's response (Ornstein et al., 2004). Thus, findings from this longitudinal study – as well as the work by Tessler and Nelson (1994) involving a sample of 4-year-olds – suggest that the nature of mother–child interaction as an event unfolds influences encoding and subsequent remembering.

Experimental work also supports this conclusion. For example, Boland et al. (2003) trained some mothers to use four specific conversational techniques to enhance their children's understanding of unfolding events: (1) Wh- questions to elicit their child's linguistic participation in the activity, (2) associations to relate that which was being experienced to what their child already knew, (3) follow-ins that

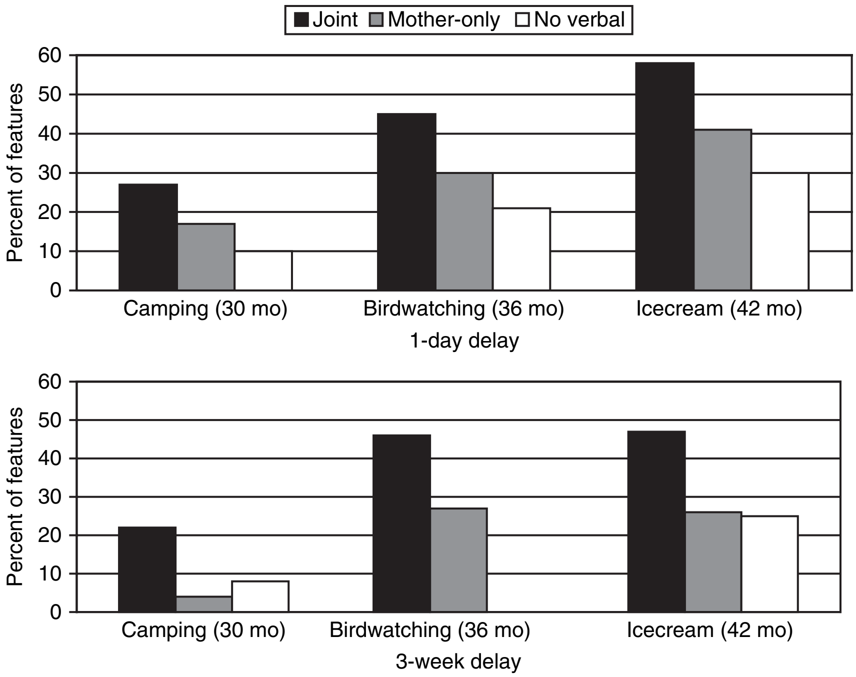


**Figure 4** Proportion of features of the camping, bird-watching, and ice-cream-store events remembered in response to open-ended questions at the 1-day and 3-week interviews, as a function of the type of talk directed toward jointly handled features. Adapted from Haden CA, Ornstein PA, Eckerman CO, and Didow SM (2001) Mother-child conversational interactions as events unfold: Linkages to subsequent remembering. *Child Dev.* 72: 1016–1031. Copyright © 2001, Blackwell.

encouraged discussion of aspects of the event in which the child was showing interest, and (4) positive evaluations to praise their child's verbal and nonverbal contributions to the interaction. After this instruction, when observed engaging with their 4-year-old children in the context of the camping event, trained mothers produced significantly more of all four of the targeted conversational techniques than did untrained mothers. Moreover, the effects of the training did not vary as a function of the children's language skills and did not impact the mothers' use of untrained techniques (i.e., repetitions, yes-no questions, and statements). Of even greater interest, the children's recall of information about the camping event was affected by the training that their mothers received. For example, the children of trained mothers exceeded those whose mothers had not received training in the production of details of the event.

Given these demonstrations of the importance of adult–child talk for children's memory performance, interesting questions concerning the potentially additive effects of conversations about the present and the past on remembering are currently being explored (McGuigan and Salmon, 2004, 2005; Conroy, 2006; Hedrick, 2006). Moreover, relatively few studies have considered how talk prior to an event may set the stage for the development of children's representations (Hudson, 2002) and the linkages between children's performance in these event memory tasks and their subsequent use of deliberate techniques for remembering (Haden et al. 2001; Lange and Carroll, 2003). We turn now to a treatment of children's developing skill in the use of these mnemonic strategies.

## 2.37.4 Learning to Be Strategic

As young children develop expertise in talking about their past experiences, they also evidence increasing skill in the use of strategies for remembering information. To a considerable extent, their growing competency in discussing the past reflects age-related improvements in the incidental encoding of information – which in turn stem from children's greater understanding of the situations that they encounter – as well as improvements in retrieving and reporting information from memory. In contrast, however, the deployment of a specific strategy for remembering – such as naming or grouping – represents intentional preparation in the service of an expected assessment of memory (Ornstein et al., 1988; Wellman, 1988; Folds et al., 1990). Given this distinction between incidental and deliberate remembering, it is interesting that even young preschoolers can demonstrate "strategic" behavior under certain circumstances. For example, when asked to remember the location of a familiar stuffed animal that was hidden in a room, 18-month-olds utilized a number of rudimentary strategies (pointing, peeking, and naming) so that the toy could be retrieved after a delay (DeLoache et al., 1985). Although the deployment of these strategic behaviors was not unambiguously related to the memory performance, these responses to a memory request do indeed suggest that children enter the preschool years with a basic understanding that remembering requires action of some sort. Nonetheless, interpretation of this finding is complicated by the fact that similar behaviors are also exhibited – but to a lesser extent – in a variation of the hide-and-seek game in which remembering is not required (DeLoache et al., 1985, Experiment 3). Consistent with Wellman's (1988) treatment of intentionality, these early mnemonic skills can be viewed as protostrategies that emerge during enjoyable activities in highly salient and meaningful situations and may not necessarily be related to later strategy acquisition (see also Ornstein et al., 1988; Folds et al., 1990).

Older preschoolers may have a firmer understanding of the need to do something in order to prepare for an assessment of memory, but the effectiveness of their efforts is analogous to that of the 18-month-olds studied by DeLoache et al. (1985). Consider, for example, a study by Baker-Ward et al. (1984) in which 4-, 5-, and 6-year-olds made use of a set of similar techniques in a memorization task with common objects. These children were directed to interact with a set of objects and toys for a 2-min period and were placed in one of three conditions: Target Remember, Target Play, and Free Play. The children in the Target Remember condition were told that they could play with all of the objects but that they should try especially to remember a subset of the items (i.e., the target objects). In contrast, the participants in the Target Play group were given instructions that did not mention remembering but rather stressed playing with a subset of the target objects, whereas those in the Free Play condition were given general play instructions.

The use of an observational coding scheme during the activity period revealed that even at age 4, the children who were told to remember behaved differently from those in the play conditions. For example, as can be seen in Figure 5, spontaneous labeling or naming occurred almost exclusively among the children in the target remember condition who were instructed to remember a subset of the objects, and it was found that these children also played less than the children in the free play and target play conditions. Moreover, as can be seen in Figure 6, the children who received instructions to remember also engaged in more visual inspection and evidenced more unfilled time than the children in the two play conditions. Unfilled time was coded when a child was not paying direct attention to the items but nonetheless did not seem to be off-task; informally, it seemed to involve reflection and self-testing. The memory instructions thus engendered a studious approach to the task among the 4-, 5-, and 6-year-olds alike, but it is important to note that only among the 6-year-olds were the strategic behaviors associated with higher levels of recall.

The literature now contains many demonstrations of what Miller (1990; see also Bjorklund and Coyle, 1995; Bjorklund et al., 1997) has termed utilization deficiencies in young children who are just beginning

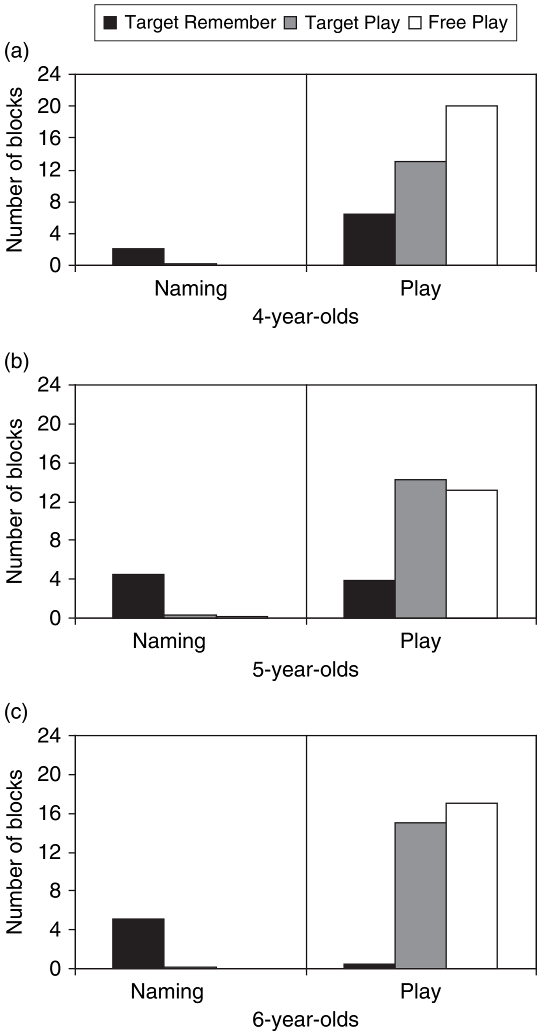


**Figure 5** Mean number of 5-s blocks of the activity period in which each naming and play occurred for the 4-year-olds (panel A), 5-year-olds (panel B), and 6-year-olds (panel C) in each instructional condition. Adapted from Baker-Ward L, Ornstein PA, and Holden DJ (1984) The expression of memorization in early childhood. *J. Exp. Child Psychol.* 37: 555–575. Copyright © 1984, Elsevier.

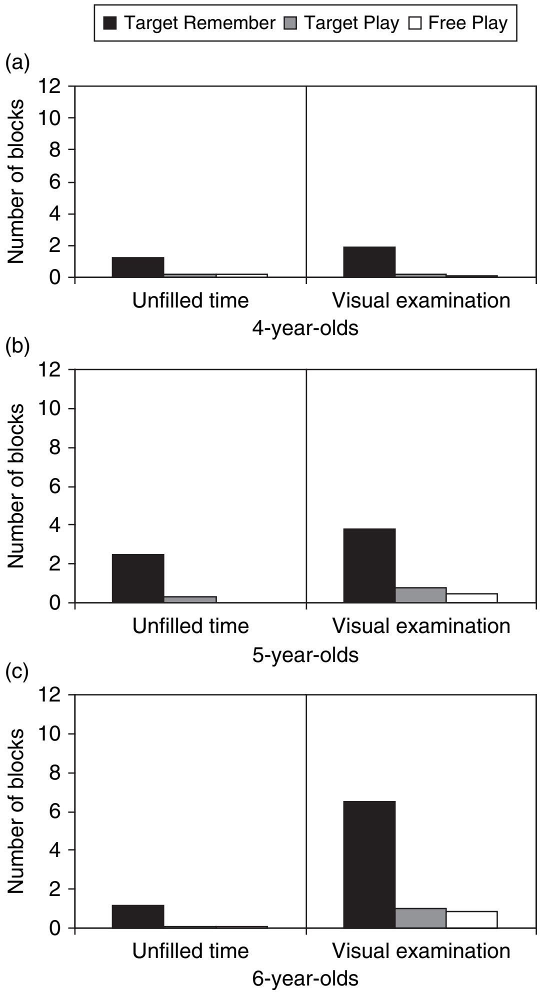


**Figure 6** Mean number of 10-s blocks of the activity period characterized by unfilled time and visual examination for the 4-year-olds (panel A), 5-year-olds (panel B), and 6-year-olds (panel C) in each instructional condition. Adapted from Baker-Ward L, Ornstein PA, and Holden DJ (1984) The expression of memorization in early childhood. *J. Exp. Child Psychol.* 37: 555–575. Copyright © 1984, Elsevier.

to generate strategies in response to memory goals. As in the Baker-Ward et al. (1984) study, strategies are produced spontaneously, but they do not seem to initially correspond to improvements in the amount recalled. Why should this be the case? If Baker-Ward et al.'s 4-, 5-, and 6-year-olds were engaging in the same strategic behaviors, why did only the efforts of the 6-year-olds have a positive effect on their recall? Moreover, why should similar strategic activities differ in their mnemonic effectiveness? Of course, it is possible that even though the observable behaviors (e.g., naming, visual inspection) of the 4-, 5-, and 6-year-olds were similar, they may have been the external manifestation of quite different underlying strategies. As such, the similarity across age in strategic efforts may be illusory, with, for example, the children of different ages combining the observable behaviors into qualitatively different strategies. That this may have been the case is suggested by Baker-Ward et al.'s observation that the younger children seemed to combine verbal naming or labeling and manipulation, whereas the older children put naming together with visual examination. It thus seems worthwhile to develop higher-order coding schemes to capture these age-related changes adequately in the coordination of different mnemonic behaviors. Efforts of this kind may well result in more precise definitions of effective mnemonic techniques, but it is also possible that such fine-grained analyses will still leave open questions about the conditions under which the application of strategies may and may not impact remembering. As discussed here, there may be other factors – for example, age related changes in underlying knowledge (Bjorklund, 1985), speed of processing (Kail, 1991), and the effort requirements of strategy usage (Guttentag, 1984; Case, 1985) – that may influence whether or not a given strategy influences remembering.

At the very least, this brief treatment of early strategies that do not work serves to highlight the fact that intentionality is only one aspect of strategic behavior and that two others – consistency and effectiveness – must be considered in any account of the development of memory. This is especially the case when it is recognized that the developmental course of children's mastery of mnemonic skills extends through the end of the elementary school years. In terms of consistency, skilled strategy users have command over a broad repertoire of mnemonic techniques (e.g., rehearsal, organization, elaboration) and are able to apply them skillfully across a broad set of situations that call for remembering (Brown et al., 1983; Ornstein et al., 1988; Pressley et al., 1989). In contrast, novice strategy users not only have a limited set of techniques at their disposal, but the very application of any given procedure is often quite context-specific and not consistent across settings. Indeed, when young children are able to demonstrate sophisticated strategy use, it typically is only in highly supportive and salient settings (Ornstein et al., 1988; Ornstein and Myers, 1996). Moreover, in terms of effectiveness, work on utilization deficiencies, discussed above, indicates that the strategic efforts of young children often do not facilitate remembering. In addition, however, even when the application of strategies does influence recall, younger children may derive less benefit than do older children (Ornstein et al., 1988; Wellman, 1988; Folds et al., 1990).

Given these complexities, longitudinal data are necessary to track on a within-individual basis developmental progress in the acquisition and deployment of strategies for remembering. Ideally, young children's increasing sophistication in the use of these techniques would be charted over time with multiple indicators of strategic competence, under conditions that vary in terms of their effort and attentional demands. Data from microgenetic research designs (Siegler and Crowley, 1991; Schlagmüller and Schneider, 2002) in which children are followed intensively for limited periods of time are also very useful for developmental analyses of mnemonic skill. Unfortunately, longitudinal and microgenetic research designs are still quite rare in the area of memory development, and our understanding of age-related changes in strategy usage stems largely from the (admittedly rich) cross-sectional literature. To illustrate strategy development, we focus here on cross-sectional studies in which an age-related progression from passive to active memorization styles has been demonstrated (Ornstein and Naus, 1985; Ornstein et al., 1988).

### 2.37.4.1 Rehearsal and Organizational Strategies in the Elementary School Years

A comparison of children's performance on tasks that assess memory for personally experienced events and those that require deliberate remembering reveals substantial differences in the levels of demonstrated sophistication. Indeed, by 8 or 9 years of age, children are very adept at providing rich reports about their experiences, but at the same time their skills appear to be quite limited in situations that call for the deployment of complex deliberate mnemonic strategies.

To illustrate the relatively late emergence of these deliberate memory skills, consider the substantially different ways in which 9- and 14-year-olds behave when given a list of words to remember and are prompted to talk aloud as the items are presented. In this type of overt rehearsal task, 9-year-olds tend to rehearse each to-be-remembered item alone as it is displayed, whereas older children (and adults) rehearse each one with several previously presented stimuli (Ornstein et al., 1975; Ornstein and Naus, 1978). To illustrate, if the first three items on a to-be-remembered list are table, car, and flower, a typical third grader would rehearse table, table, table, when the first word is shown; car, car, car, when car is presented; and flower, flower, flower, when the third word is shown. In contrast, the average 14-year-old is likely to rehearse table, table, table, when table is presented; table, car, table, car, when car is presented; and table, car, flower, when flower is displayed. These children thus differ considerably in the extent to which rehearsal is limited (or passive) versus more cumulative (or active), and these differences in rehearsal style are related to substantial differences in recall. Indeed, with increases in age, not only does rehearsal become more active – with several different items being intermixed – but recall improves dramatically, especially that of the early list items. That is, children's increasingly active rehearsal styles are associated with improved recall of the primary section of the serial position curve (Ornstein et al., 1975).

These changes in the use of rehearsal are paralleled by comparable developments in the deployment of organizational strategies for remembering. Consider, for example, the performance of third and fourth graders on a sort-recall task in which they are given a set of low-associated words (or pictures) and asked to "form groups that will help you remember." Under these conditions, in which the items are sorted prior to each recall trial, children as old as 9 years of age tend not to form groups on the basis of semantic relations among the to-be-remembered materials but, rather, establish what seem to be randomly arranged groupings that vary considerably over trials (Liberty and Ornstein, 1973; Bjorklund et al., 1977). In dramatic contrast, children aged 12 and older routinely establish groups that are semantically constrained, even though the memory instructions do not prompt sorting on the basis of meaning. These older individuals seem to have the metacognitive understanding that sorting on the basis of meaning will facilitate recall, readily translating a remembering instruction into one that involves a search for a meaning-based organization (Ornstein et al., 1974). Moreover, consistent with the rehearsal literature, these age differences in the extent to which sorting is driven by the semantic organization of the materials are associated with corresponding differences in recall. However, it should be emphasized that younger children's failure to use a meaning-based grouping strategy does not imply that they lack understanding of the semantic linkages among the items, as they can readily sort even low-associated items on the basis of meaning when instructed to do so (Bjorklund et al., 1977; Corsale and Ornstein, 1980). As such, the age differences in performance would seem to reflect age differences in understanding how underlying knowledge can be applied strategically in the service of a memory goal.

### 2.37.4.2 Context Specificity in Strategy Development

These age-related differences in rehearsal and sorting represent a sampling from a now-extensive literature on children's developing skills in the use of a variety of strategies for remembering (Schneider and Pressley, 1997; Schneider and Bjorklund, 1998; Bjorklund et al., in press). Although the bulk of this literature is composed of cross-sectional studies, it is nonetheless clear that with increases in age there are corresponding increases in rehearsal, organization, elaboration, and other techniques that influence the encoding, storage, retrieval, and reporting of information. Further, demonstrations of the ways in which older and young children differ in the deployment of mnemonic strategies have been supplemented by training studies so as to document causal linkages between strategy use and remembering. To illustrate, the provision of minimal instructions to rehearse several items together is sufficient to increase the recall of younger children, and prompts to rehearse each item on a list alone or in relative isolation can reduce the recall of older children (Ornstein et al. 1977; Ornstein and Naus, 1978). Similarly, when young children are required by a yoking procedure to follow the more semantically constrained sorting pattern of older children or adults, their recall is facilitated, and when adults are yoked to these sorts of young children, their recall is reduced (Liberty and Ornstein, 1973; Bjorklund et al., 1977). Children's sorting of low-associated materials can also be manipulated – with corresponding effects on their remembering – by simply instructing them to sort on the basis of meaning (Bjorklund et al., 1977; Corsale and Ornstein, 1980) or by exposing them to materials that are highly organized (Best and Ornstein, 1986).

It is thus clear that there are causal linkages between children's strategic efforts and their recall performance. However, it is also the case that there are limits to the success of these experimental interventions that shed light on other factors that contribute to effective strategy production. For example, although third graders can follow instructions to rehearse several items together, their use of such an active rehearsal strategy does not increase their recall to the level of sixth graders (Ornstein et al., 1977). This failure to eliminate age differences in remembering most likely stems from the fact that the use of an active rehearsal strategy requires that young children expend more of their attentional resources than is necessary for older children (Guttentag, 1984). Consistent with Guttentag's observation that the attentional demands of an active rehearsal strategy may vary at different points in development, it certainly is easier for young children to rehearse several items together when the effort demands of the task are reduced. Thus, for example, when instructions to rehearse actively are combined with a procedure in which children have continued visual access to each to-be-remembered item after its initial presentation, striking improvements in strategy use and subsequent recall are noted (Ornstein et al., 1985). Although effort demands are also important in the context of organizational strategies (see Bjorklund and Harnishfeger, 1987), when children of different ages have comparable understanding of the to-be-remembered items and are led by instructions to use this knowledge as a basis for their sorting, recall differences are generally eliminated (Corsale and Ornstein, 1980).

Although context can certainly affect the outcome of training manipulations, it can also influence the degree to which children will engage spontaneously in strategic activities, as well as the sophistication of their efforts. To illustrate, the manipulation mentioned above to reduce the effort demands of an instructed active rehearsal strategy – permitting children to view all previously presented items – has been shown to increase the likelihood of spontaneously making use of a cumulative rehearsal strategy. Indeed, Guttentag et al. (1987) observed that some third graders who typically rehearsed passively when the to-be-remembered items were presented in the typical fashion changed to a multi-item rehearsal strategy without prompting when given an opportunity to continue to see all items. In addition, consistent with the finding discussed above that prior knowledge can impact children's reports of previously experienced events, knowledge and understanding of the materials can dramatically influence children's use of mnemonic strategies when acting in the service of a memory goal (Bjorklund, 1985; Ornstein and Naus, 1985). Indeed, increases with age in the contents of the knowledge base and the ease with which stored information may be accessed have serious implications for the deployment of strategies. What a child knows about the items to be remembered can certainly determine just what can – and cannot – be done strategically with those materials. At one extreme, a child may not be able execute a grouping strategy at all if he or she does not know the category structure of the to-be-remembered materials, but even when children are familiar with the meaning of the materials, they may nonetheless appear to be strategic when given some items to remember and nonstrategic with others (Ornstein and Naus, 1985; Ornstein et al., 1988).

These demonstrations of the impact of the materials on remembering have led to the suggestion that the children's first expressions of deliberate memorization will be observed when they are presented with highly meaningful materials in very salient contexts (Ornstein et al., 1988). This was illustrated above in the discussion of Baker-Ward et al.'s (1984) study in which 4-, 5-, and 6-year-olds could interact with a set of toys and objects under remember- or play-based instructions. With these very salient materials, the 4-year-olds engaged in strategic behaviors when told to remember, even though their efforts did not facilitate remembering. In addition, although it is known that third graders do not sort low-associated items in terms of their underlying meaning when told to "form groups that will help you remember" (Bjorklund et al., 1977), as discussed earlier, when given more salient, categorically related items, they will readily group on the basis of meaning when given the typical memory-based instruction (Corsale, 1978). It seems likely that the saliency of the category structure is so powerful that it is difficult not to sort in an organized manner. Similar effects of the dependence of memory strategies on the stimulus properties of to-be-remembered materials can be seen in Tarkin's (1981; see also Ornstein et al., 1988) exploration of third graders' use of rehearsal strategies. Further, it is likely that the increasing articulation of the knowledge system with age and experience may facilitate information retrieval and thus reduce the amount of attentional effort required to implement various subcomponents of memory strategies (Ornstein et al., 1988).

### 2.37.4.3 The Development of Effective Strategy Use

With increases in age, the context specificity that characterizes early strategy use is reduced, as children extend the range of settings in which they behave in a strategic fashion (Ornstein et al., 1988). In parallel with this generalization of strategy use, their strategic efforts become increasingly effective in facilitating remembering. Two features of this change in the efficacy of children's strategic efforts are discussed briefly, followed by a treatment of some of the factors that may underlie these age-related changes.

First, as already indicated, there are substantial age-related changes in what children actually do when confronted with a memory goal. Younger children, for example, are more likely than older children to select strategies that are inappropriate for a task, as, for example, when preschoolers implement deliberate strategies that do not facilitate performance in any way (see Wellman, 1988, for a treatment of faulty strategies). Moreover, when children of elementary school age are asked to remember verbal materials, there is a general progression from more passive, rote-type mnemonic techniques to more active strategies that seem to involve deliberate efforts at integrating the material being remembered with existing knowledge. Further, with increases in age, children have increased numbers of strategies at their disposal and are better able to make flexible use of this mnemonic repertoire (Folds et al., 1990; Schneider and Bjorklund, 1998). Second, even when the same strategy appears to be employed by children of different ages, the technique typically has a more facilitative effect on the memory of older as opposed to younger children. As indicated above, Baker-Ward et al. (1984) showed that 4-, 5-, and 6-year-olds all utilized strategies when trying to remember a set of objects, but these techniques only facilitated the memory performance of the oldest group of children. These data – and other demonstrations of utilization deficiencies (Miller 1990; Bjorklund and Coyle 1995) – again show that even very young children may be aware of the importance of implementing a strategy in the service of remembering, but that the strategies that they nominate may be largely ineffective.

### 2.37.4.4 Factors Underlying Developmental Changes in Strategic Memory

In an effort to understand changes in strategy deployment and effectiveness, we turn now to a brief treatment of several factors that may impact children's use of strategies and serve as mediators of the observed age-related progression: (1) Changes in the underlying knowledge base in memory, (2) reductions in the effort requirements of strategy implementation, (3) increases in metamnemonic understanding, and (4) experiences in formal schooling.

#### *2.37.4.4.1 Prior knowledge*

As discussed earlier in our treatment of knowledge and event memory, changes with age in both the content and structure of children's underlying knowledge in permanent memory can influence dramatically the flow of information within the memory system and thus affect overall performance (Chi, 1978; Bjorklund, 1985; Ornstein and Naus, 1985). Moreover, in recent years there has been a consensus among memory researchers that both knowledge and strategy use contribute in important ways to the development of children's deliberate memory skills (Ornstein et al., 1988; Muir-Broaddus and Bjorklund, 1990) and recognition that under some conditions, the impact of the knowledge base may be mediated by its effects on strategy implementation (Ornstein and Naus, 1985; Rabinowitz and McAuley, 1990). This emerging perspective emphasizes the impact that the current state of a child's knowledge system may have on both strategy selection and execution (Ornstein et al., 1988; Folds et al., 1990). Indeed, as illustrated previously in our treatment of context specificity, young children may appear to be quite strategic in supportive settings when presented with highly salient and meaningful sets of materials, but they may seem to be much more tentative, and even astrategic, when presented with less structured items.

How should these demonstrations of context specificity in strategy use be interpreted? As mentioned previously, one explanation for the sometimes dramatic differences in the performance of young children under contrasting task demands is that they may not have sufficient knowledge about the materials to carry out appropriate strategies. Indeed, knowing the meaning and categorical structure of a set of words is a necessary, albeit not sufficient, prerequisite for implementing a semantically based clustering strategy. A second explanation focuses on the beneficial effects of knowledge on the efficiency of mnemonic processing. With increases in age and experience, the knowledge system becomes increasingly articulated, with rich interconnections among items, thereby contributing to the ease of access that is needed for the skillful execution of strategies such as active rehearsal and meaning-based sorting (Bjorklund, 1987; Ornstein et al., 1988; Bjorklund et al., 1990). Interestingly, these developments in the underlying knowledge base – with the increased likelihood of the automatic activation of strong associative links – may thus make young children's strategic efforts not entirely deliberate (Lange, 1978; Bjorklund, 1985). At the same time, however, these associative links may increase the efficiency and effectiveness of the strategy use of older children. Finally, these developments in the knowledge system may contribute to age-related increases in the likelihood that children will spontaneously use their underlying knowledge strategically when confronted with memory goals (Corsale and Ornstein, 1980).

#### 2.37.4.4.2 Effort requirements of strategy use

Age-related changes in the effectiveness of children's strategies may also reflect corresponding differences in the attentional resources that are needed for the execution of mnemonic techniques. If one assumes a type of tradeoff between the processing and storage operations that are involved in carrying out any given cognitive task (Case, 1985), then in the early stages of acquiring a skill such as cumulative rehearsal, strategy execution may so tax the limited capacity system that little remains to be allocated to encoding and storage processes (Bjorklund and Harnishfeger, 1987). Consistent with this perspective, a child may be able to deploy a given memory strategy under some conditions, but the effort required to do so may be so great that the strategy does not actually facilitate performance. Indeed, as indicated earlier, Guttentag (1984) demonstrated that second graders may be capable of producing an active rehearsal strategy when so instructed, but that their deployment of this technique is more demanding of their limited capacity than is the case for older children or adults (see also Bjorklund and Harnishfeger, 1987; Kee and Davies, 1988). As suggested above, evidence consistent with this finding was reported by Guttentag et al. (1987), who found that some children who typically rehearsed passively were able to change to active rehearsal when the resource demands of this more complex strategy were reduced.

If we assume that young children may expend more of their cognitive resources on the processing component of strategy execution than older children, what factors underlie improvements with age in processing efficiency? Three possibilities can be mentioned. First, speed of information processing (e.g., Kail, 1991) increases markedly across the elementary school years, a change that is largely the result of maturation. Second, as indicated earlier, the development of the knowledge base – in terms of the greater coherence of the semantic network and increased ease of accessibility – may also contribute to increases in efficiency of strategy execution (Bjorklund, 1987). Third, the functional capacity of the system may increase with age because specific aspects of a task may come to require fewer resources, reflecting the increased automatization of skill that is associated with experience and practice (Case, 1985; Ornstein et al., 1988; Siegler, 1996).

#### 2.37.4.4.3 Metamemory

It is well documented that with increases in age, there also are changes in children's metamemory, that is, in their understanding of the demands of various memory tasks and of the operation of the memory system (Flavell and Wellman, 1977; Cavanaugh and Perlmutter, 1982; Schneider, 1985). It must be indicated, however, that even though metamemory figures prominently in accounts of mnemonic growth (e.g., Cavanaugh and Borkowski, 1980; Schneider, 1985), the results of correlational studies in which both memory and metamemory have been assessed have been quite mixed. Examples of some of the difficulties encountered in providing evidence for the proposed linkage between metamnemonic understanding and strategic deployment and effectiveness include cases in which children can articulate awareness of a memory strategy but nonetheless fail to actually use it in practice (Sodian et al., 1986), and in contrast, situations in which children use what might be viewed as a deliberate strategy but are unable to demonstrate any corresponding metamnemonic knowledge (Bjorklund and Zeman, 1982). On the other hand, both early training studies in which strategy instruction was supplemented by the provision of metamnemonic information (e.g., Paris et al., 1982), and more recent studies involving improved methods of assessing young children's understanding (e.g., Schneider et al., 1998; Schlagmüller and Schneider, 2002), provide convincing empirical evidence for the linkage between metamemory and memory development. For example, in a short-term longitudinal study, Schlagmüller and Schneider (2002) reported that children who acquired an organizational strategy over the course of the project actually showed increases in declarative metamemory well ahead of actually exhibiting the strategy.

#### *2.37.4.4.4 Schooling*

A number of lines of evidence lead to the inference that formal schooling may contribute to the development of children's increasing skill in the use of memory strategies. Consider, for example, comparative cultural investigations in which the performance of children who were matched in chronological age but who differed in terms of whether they had or had not participated in Western-style schooling have been contrasted. In studies carried out in Liberia (e.g., Scribner and Cole, 1978), Mexico (e.g., Rogoff, 1981), and Morocco (e.g., Wagner, 1978), children who attended school demonstrated superiority in the types of mnemonic skills that have typically been studied by Western psychologists and anthropologists. To illustrate, Rogoff (1981) reported that nonschooled children generally do not make use of organizational techniques for remembering unrelated items and that school seemed necessary for the acquisition of these skills. These findings, of course, do not in any way imply that schooled children outperform their unschooled peers on everyday memory tasks that are embedded in activities central to their culture. Nonetheless, they do suggest that something in the formal school context most likely is related to the emergence of skills that are important for success on tasks that involve deliberate memorization.

With comparative-cultural research indicating that something about formal schooling encourages the development of strategic behavior, the next question might be, When during a child's experience in school does this growth occur? First grade seems to be a strong possibility, as Morrison et al. (1995) showed that this grade is very important in terms of the development of memory skills. Morrison and his colleagues studied children who just made the mandated date for entry into first grade (a young first-grade group) and those who just missed the date (an old kindergarten group). As such, the children were basically matched in terms of age but nonetheless differed in their school experience, thus allowing for a comparison between a first-grade school experience and a kindergarten experience. To assess memory, Morrison et al. (1995) used a task (adapted from Baker-Ward, 1985) in which the children were asked to study a set of pictures of common objects. Taking performance at the start of the school year as a baseline, the young first graders evidenced substantial improvement in their memory skills. In contrast, the performance of the older kindergartners did not change over the year, although improvement was noted the next year, following their experience in the first grade. These findings imply that there is something in the first-grade context that is supportive of the development of children's memory skills. The potential importance of the first-grade experience is also suggested by Baker-Ward et al.'s (1984) finding, discussed above, that the strategic efforts of 4-, 5-, and 6-year-olds only facilitated the memory performance of the older children.

Given that the evidence points to formal schooling as a mediator of children's strategy development, Ornstein et al. (in press) have carried out a series of studies to characterize memory-relevant behaviors that teachers use that may support children's deliberate memory skills. Some of their findings are consistent with Moely et al.'s (1992) important report that it is quite rare to find explicit instruction in mnemonic techniques by teachers throughout the elementary school grades. However, even though mnemonic strategies are not generally taught by teachers in an explicit fashion, Ornstein and his colleagues find that first-grade teachers engage in a variety of memory-relevant behaviors in the course of whole-class instruction, including indirect requests for deliberate remembering, strategy suggestion, and metacognitive questioning. Moreover, children in first-grade classes taught by teachers who use more of this sort of memory-related language show a greater ability to take advantage of strategy training (meaning-based sorting and clustering in recall according to semantic categories) than those children with low-mnemonically oriented teachers (Coffman et al., 2003; see Moely et al., 1992, for similar results). In addition, teachers' mnemonic style in the first grade is linked to the organized sorting patterns on a sort-recall task with low-associated items that was administered to the children 3 years later, such that fourth graders who had been taught by high-mnemonic first-grade teachers sorted more semantically than did their peers who had been taught by low-mnemonic first-grade teachers. As such, this work suggests that just as 'parent talk' about events can impact preschoolers' developing abilities to remember (e.g., McCabe and Peterson, 1991; Reese et al., 1993; Haden et al., 2001; Boland et al., 2003), 'teacher talk' may also be relevant for the emergence and refinement of mnemonic skills.

#### 2.37.4.5 Determinants of Performance and Development

The research on children's strategy development reviewed here suggests that knowledge, effort, metamemory, and schooling can be viewed as mediators of the performance of children at any given age. These determinants of memory performance may also underlie developmental changes in strategic deployment and effectiveness. Changes with age in children's knowledge of the materials being remembered, the cognitive effort they need to execute tasks that involve remembering, and their understanding of the operation of the memory system all can contribute to age-related increases in strategic effectiveness. However, we attach special status to schooling as a potential mediator of change because the available evidence suggests that school represents a critical context for the emergence and consolidation of children's mnemonic efforts. Further, as suggested in our discussion of schooling, it seems likely that teacher–child conversation in the classroom is of great relevance for the development of a repertoire of strategies.

### 2.37.5 Exploring the Development of Memory

The research literature reviewed here provides a picture of the quite remarkable mnemonic competence of young children, as well as clear age-related differences in many aspects of memory performance. Much is thus known about memory development, that is, the memory skills of children of different ages, but much less is known about the development of memory in the sense of understanding the ways in which early instantiations of skill give way to later competencies, and the factors that serve to explain these changes. It also must be admitted that even understanding of memory development, while substantial, is nonetheless limited and that much remains to be learned about children's skills at various ages.

Why are there substantial gaps in what we know about memory and its development? To a considerable extent, the problem stems from the methodological choices typically made by researchers. Consider first the paradigm-driven nature of work on children's memory. Most studies of memory deal with remembering in the context of one or another task (many of which have been discussed here), and as a result, relatively little is known about linkages across tasks that vary in terms of their processing demands and other important characteristics. Yet this is exactly the type of information that is necessary to characterize adequately children's skills at any given age and to identify just what is changing with age and experience. For example, just as Bauer (2006) compared infants' abilities to imitate enabling versus arbitrary action sequences, thus providing useful diagnostic information, within-subjects contrasts in strategy use under different conditions could yield valuable insights into the memory skills of elementary school children and their development. As an example, Guttentag et al.'s (1987) description of children's rehearsal under typical (i.e., each item removed after being presented) and scaffolded (i.e., each item remained visible after being presented) conditions provides important information about skills that are in transition.

A second methodological preference of researchers also seriously hinders our understanding of developmental change. As suggested earlier, because the bulk of the literature is based on cross-sectional experiments, little can be said about the course of developmental change within individual children. Cross-sectional studies present useful accounts of the average level of competence on specified tasks at particular age levels, and the impression one derives is that of a smooth developmental pattern. However, there is nothing in a cross-sectional study that enables inferences about the course of development of an individual child or contrasting patterns of change for different groups of children. Moreover, putting both methodological concerns together, the rich cross-sectional literature can say nothing about how early skill in, say, elicited imitation relates to later ability in talking about the past, and still later competence in settings in which deliberate memorization is required. For information of this sort, it is necessary to make use of longitudinal research designs in which the development of skill is traced over time, with children being assessed on a range of contrasting tasks. Microgenetic studies (Siegler, 2006) in which children are tested repeatedly over relatively restricted periods of time during which skills are undergoing change can also be invaluable in informing our understanding of development.

The challenge, then, is for a commitment to research designs that truly can facilitate our understanding of the development of memory. Such a commitment requires a willingness to move across the sometimes cherished conceptual boundaries of different subgroups of researchers, for example, those of the information processing and the social constructivist traditions. It may be useful to think about the encoding, storage, and retrieval of information in information processing terms, and it may be equally productive to think about the forces that propel development from the perspective of social constructivism. This is especially the case when, as suggested above, children's developing memory skills may be fostered by social interaction with parents and teachers. By integrating these methods – and by including multiple assessments of children on tasks that are selected because of their contrasting information processing demands – it is possible to provide more precise cognitive diagnoses of children's changing skills as well as some insight into the social forces that drive development.

To illustrate the importance of longitudinal research for an understanding of development, consider first two longitudinal studies, one dealing with children's event recall in the context of the mother–child reminiscing work discussed above (Reese et al., 1993), and the other concerned with the development of active rehearsal strategies in deliberate memory tasks, also mentioned earlier (Guttentag et al., 1987). Admittedly, each of these studies is somewhat limited by a focus on only a single indicator of mnemonic competence and by the age range examined, but they nonetheless can serve to illustrate some of the benefits of this research strategy. For example, Reese et al. reported that the children of high-elaborative mothers showed higher levels of recall of the events under discussion (as assessed by their production of memory elaborations) than the children of low-elaborative mothers. However, what is unique about this study is the finding that, in the context of these mother–child interactions, the children acquired some generalized skills for remembering that had implications for their performance several years later. Thus, for example, levels of maternal elaboration early in development (at 40 months of age) are positively correlated with the children's skills in making independent contributions to these conversations at later points in time (e.g., at 58 and 70 months).

Guttentag et al.'s (1987) exploration of changes in verbal rehearsal from the third to the fourth grade complements Reese et al.'s (1993) event memory study. As suggested above, Guttentag and his colleagues were concerned with the effort requirements of active, cumulative rehearsal and reported that the rehearsal style of some third graders varied as a function of mode of presentation. In particular, some of the children who rehearsed in a passive fashion under the typical mode of presentation changed to a more active rehearsal pattern spontaneously when they were permitted visual access to the previously presented items. Turning this study into a short-term longitudinal investigation, Guttentag et al. assessed the children again after 1 year, when they were in the fourth grade. Interestingly, the researchers reported that the fourth graders' use of an active rehearsal technique under typical item-by-item presentation conditions was better predicted by what they could do as third graders in the scaffolded than the standard version of the task. They suggested that it was possible to view the children who evidenced active rehearsal as third graders when given visual access to the materials as being in a transitional stage of competence.

Other important insights into development are derived from two separate longitudinal studies of children's developing memory strategies that have been carried out by Schneider and his colleagues. In the first investigation (the Munich Longitudinal Study on the Genesis of Individual Competencies; Sodian and Schneider, 1999), children were tracked between 4 and 18 years of age, whereas in the second study (the Würzburg Longitudinal Memory Study; Schneider et al., 2004), a separate sample of children was observed multiple times between 6 and 9 years of age. Although the studies varied in a number of respects, a consistent pattern that emerges is that strategy development is not as gradual as the cross-sectional data discussed here would lead one to believe. In particular, in both investigations, the improvements that children showed in strategy use reflect a picture of dramatic leaps in performance and not gradual increases in sophistication over time.

Related to longitudinal investigations are microgenetic studies that feature frequent and intense observations of the same child across repeated sessions over relatively short intervals. Several unique insights have been gained from these types of investigation that provide new information concerning the emergence and consolidation of children's strategic efforts. First, Siegler's (2006) exploration of a variety of cognitive strategies suggests that children often use less effective techniques in tandem with more sophisticated and efficient strategies that have been recently acquired. In an important treatment of these patterns, Siegler (1996) describes strategy development in terms of an overlapping waves theory with elementary school children having mastery of a mix of strategies at any point in time, and development being viewed in terms of changes in the composition of this strategy mix. Consistent with this position, in their longitudinal study of developmental changes in rehearsal, Lehman and Hasselhorn (2007) observed that more than half of the children utilized two or more strategies within each measurement point, suggesting that they are making use of multiple strategies (e.g. naming, cumulative rehearsal) for remembering. Second, consistent with the Munich and Würzburg investigations, the results of microgenetic analyses confirm the fact that children do not always transition from rudimentary to complex strategies in a gradual fashion over time (Kuhn, 1995). Consider, for example, Schlagmüller and Schneider's (2002) microgenetic study of the development of a categorization strategy in the context of a sort–recall task. Fourth- and fifth-grade children, who had been identified as nonstrategy users in the context of the Würzburg longitudinal study of memory development, were given nine sort–recall tasks over the course of an 11-week period. Importantly, those children who adopted the organizational strategy did so in an all-or-none fashion at different times, with some children never categorizing during the task. However, once children came to organize the materials, immediate improvements in recall were observed and were linked to metamnemonic insights immediately prior to strategy acquisition.

## 2.37.6 Closing Thoughts

It is clear that longitudinal and microgenetic analyses of children's memory can extend the cross-sectional database in critical ways by providing a truly developmental account of the acquisition of skill. Although cross-sectional studies can generate valuable information about the abilities of children of different ages, thus suggesting age-related trends, statements about development within individuals can only be made when researchers employ designs in which the changing abilities of the same children are tracked over time. However, to be truly informative, longitudinal studies must be designed so as to identify potential mediators – such as adult–child conversations – of developmental change. Nonetheless, these important features of longitudinal investigations notwithstanding, it must be emphasized, as well, that they are not without their limitations. Indeed, most explorations of cognitive development that incorporate repeated assessments of children are correlational in nature, and as such, it is difficult to make statements about causation. It is thus essential to supplement these within-subjects approaches with experimental interventions in which variables of theoretical importance – such as the nature of the conversation to which children are exposed – are brought under experimental control. In fact, in the ideal research world, we envision an integrated methodological approach in which longitudinal studies that enable us to track children's skills and identify potential determinants of development are paired with training studies in which these mediators are explored experimentally. In this way, it should be possible to study both memory development and the development of memory.

## References


Adolph KE (1997) *Learning in the Development of Infant Locomotion. Monographs of the Society for Research in Child Development*. 62(3 Serial No. 251). Malden, MA: Blackwell.

Baker-Ward LE (1985) *An Exploration of Memorization in Kindergarten Children*. PhD Thesis, University of North Carolina at Chapel Hill, NC.

Baker-Ward L, Ornstein PA, and Holden DJ (1984) The expression of memorization in early childhood. *J. Exp. Child Psychol.* 37: 555–575.

Baker-Ward L, Ornstein PA, and Principe GF (1997) Revealing the representation: Evidence from children's reports of events. In: van den Broek PW, Bauer PJ, and Bourg T (eds.) *Developmental Spans in Event Comprehension and Representation: Bridging Fictional and Actual Events*, pp. 79–107. Hillsdale, NJ: Erlbaum.

Baker-Ward L, Gordon BN, Ornstein PA, Larus DM, and Clubb P (1993) Young children's long-term retention of a pediatric examination. *Child Dev.* 64: 1519–1533.

Barr R, Dowden A, and Hayne H (1996) Developmental changes in deferred imitation by 6- to 24-month-old infants. *Infant Behav. Dev.* 19: 159–170.

Barr R and Hayne H (2000) Age-related changes in imitation: Implications for memory development. In: Rovee-Collier C, Lipsitt LP, and Hayne H (eds.) *Progress in Infancy Research,* vol. 1, pp. 21–67. Hillsdale, NJ: Erlbaum.

Bauer PJ (1996) What do infants recall of their lives? Memory for specific events by one-to two-year-olds. *Am. Psychol.* 51: 29–41.

Bauer PJ (2006) Event memory. In: Kuhn D, Siegler RS, Damon RS, and Lerner RM (eds.) *Handbook of Child Psychology, vol. 2, Cognition, Perception, and Language* 6th edn., pp. 373–425. Hoboken, NJ: Wiley.

Bauer PJ (2007) *Remembering the Times of Our Lives: Memory in Infancy and Beyond*. Mahwah, NJ: Erlbaum.

Bauer PJ and Burch MM (2004) Developments in early memory: Multiple mediators of foundational processes. In: Lucariello JM, Hudson JA, Fivush R, and Bauer JP (eds.) *The Development of the Mediated Mind*, pp. 101–125. Mahwah, NJ: Erlbaum.

Bauer PJ, Hertsgaard LA, and Wewerka SS (1995) Effects of experience and reminding on long-term recall in infancy: Remembering not to forget. *J. Exp. Child Psychol.* 59: 260–298.

Bauer PJ and Travis LL (1993) The fabric of an event: Different sources of temporal invariance differentially affect 24-month-olds' recall. *Cogn. Dev.* 8: 319–341.

Bauer PJ, Wenner JA, Dropik PL, and Wewerka SS (2000) *Parameters of Remembering and Forgetting in the*

*Transition from Infancy to Early Childhood. Monographs of the Society for Research in Child Development,* 65 (4, Serial No. 263). Malden, MA: Blackwell.
Bauer PJ and Wewerka SS (1995) One- to two-year-old's recall of events: The more expressed, the more impressed. *J. Exp. Child Psychol.* 59: 475–496.
Bauer PJ, Wiebe SA, Waters JM, and Bangston SK (2001) Reexposure breeds recall: Effects of experience on 9-month-olds' ordered recall. *J. Exp. Child Psychol.* 80: 174–200.
Bauer PJ, Wiebe SA, Carver LJ, Waters JM, and Nelson CA (2003) Developments in long-term explicit memory later in the first year of life. *Psychol. Sci.* 14: 629–635.
Best DL and Ornstein PA (1986) Children's generation and communication of mnemonic organizational strategies. *Dev. Psychol.* 22: 845–853.
Binet A and Henri V (1894) La mémoire des mots. *Année Psychol.* 1: 1–23.
Binet A and Henri V (1894a) La mémoire des phrases (mémoire des idées). *Année Psychol.* 1: 24–59.
Bjorklund DF (1985) The role of conceptual knowledge in the development of organization in children's memory. In: Brainerd CJ and Pressley M (eds.) *Basic Processes in Memory Development*, pp. 103–142. New York: Springer.
Bjorklund DF (1987) How changes in knowledge base contribute to the development of children's memory: An interpretive review. *Dev. Rev.* 7: 93–130.
Bjorklund D (1990) *Children's Strategies: Contemporary Views of Cognitive Development*. Hillsdale, NJ: Erlbaum.
Bjorklund DF and Coyle TR (1995) Utilization deficiencies in the development of memory strategies. In: Weinart FE and Schneider W (eds.) *Memory Performance and Competencies: Issues in Growth and Development*, pp. 161–180. Mahwah, NJ: Erlbaum.
Bjorklund DF, Dukes C, and Brown RD (in press) The development of memory strategies. In Courage M and Cowan N (eds.) *The Development of Memory in Childhood*, 2nd edn. Hove: Psychology Press.
Bjorklund DF and Harnishfeger KK (1987) Developmental differences in the mental effort requirements for the use of an organizational strategy in free recall. *J. Exp. Child Psychol.* 44: 109–125.
Bjorklund DF, Miller PH, Coyle TR, and Slawinski JL (1997) Instructing children to use memory strategies: Evidence of utilization deficiencies in memory training studies. *Dev. Rev.* 17: 411–442.
Bjorklund DF, Muir-Broaddus JE, and Schneider W (1990) The role of knowledge in the development of children's strategies. In: Bjorklund DF (ed.) *Children's Strategies: Contemporary Views of Cognitive Development*, pp. 93–128. Hillsdale, NJ: Erlbaum.
Bjorklund DF, Ornstein PA, and Haig JR (1977) Developmental differences in organization and recall: Training in the use of organizational techniques. *Dev. Psychol.* 13: 175–183.
Bjorklund DF and Zeman BR (1982) Children's organization and metamemory awareness in the recall of familiar information. *Child Dev.* 53: 799–810.
Boland AM, Haden CA, and Ornstein PA (2003) Boosting children's memory by training mothers in the use of an elaborative conversational style as an event unfolds. *J. Cogn. Dev.* 4: 39–65.
Borovsky D and Rovee-Collier C (1990) Contextual constraints on memory retrieval at six months. *Child Dev.* 61: 1569–1583.
Brainerd CJ, Kingma J, and Howe ML (1985) On the development of forgetting. *Child Dev.* 56: 1103–1119.
Brainerd CJ, Reyna VF, Howe ML, and Kingma J (1990) *The Development of Forgetting and Reminiscence. Monographs of the Society for Research in Child Development,* 55, pp. 3–4. Malden, MA: Blackwell.
Brown AL, Bransford JD, Ferrara RA, and Campione JC (1983) Learning, remembering, and understanding. In: Flavell JH, Markman EM, and Mussen PH (eds.) *Handbook of Child Psychology, vol. 3. Cognitive Development*, pp. 77–166. New York: Wiley.
Burgwyn-Bailes E, Baker-Ward L, Gordon BN, and Ornstein PA (2001) Children's memory for emergency medical treatment after one year: The impact of individual difference variables on recall and suggestibility. *Appl. Cogn. Psychol.* 15: S25–S48.
Campbell AA and Jaynes J (1966) Reinstatement. *Psychol. Rev.* 73: 478–480.
Carr M, Kurtz BE, Schneider W, Turner LA, and Borkowski JG (1989) Strategy acquisition and transfer among American and German children: Environmental influences on metacognitive development. *Dev. Psychol.* 25: 765–771.
Carver LJ and Bauer PJ (2001) The dawning of a past: The emergence of long-term explicit memory in infancy. *J. Exp. Psychol. Gen.* 130: 726–745.
Case R (1985) *Intellectual Development: Birth to Adulthood*. Orlando: Academic Press.
Cavanaugh JC and Borkowski JG (1980) Searching for metamemory-memory connections: A developmental study. *Dev. Psychol.* 16: 441–453.
Cavanaugh JC and Perlmutter M (1982) Metamemory: A crucial examination. *Child Dev.* 53: 11–28.
Ceci SJ and Bruck M (1993) Suggestibility of the child witness: A historical review and synthesis. *Psychol. Bull.* 113: 403–439.
Ceci SS and Bruck M (1995) *Jeopardy in the Courtroom: A Scientific Analysis of Children's Testimony*. Washington, DC: APA.
Ceci SJ, Ross DR, and Toglia MP (1987) Suggestibility of children's memory: Psycholegal implications. *J. Exp. Psychol. Gen.* 116: 38–49.
Chi MTH (1978) Knowledge structure and memory development. In: Seigler RS (ed.) *Children's Thinking: What Develops?* Hillsdale, NJ: Erlbaum.
Chi MTH and Ceci SJ (1987) Content knowledge: Its role, representation, and restructuring in memory development. In: Reese HW (ed.) *Advances in Child Development and Behavior,* vol. 20, pp. 91–142. New York: Academic Press.
Clubb PA, Nida RE, Merritt K, and Ornstein PA (1993) Visiting the doctor: Children's knowledge and memory. *Cogn. Dev.* 8: 361–372.
Coffman JL, Ornstein PA, and McCall LE (2003) Linking teachers' memory relevant talk to children's memory performance. Poster presented at the biennial meeting of the Society for Applied Research in Memory and Cognition, Aberdeen, Scotland.
Conroy R (2006) *Children's Memory for Traumatic Events: The Influence of Post-Event Avoidance and Elaboration.* PhD Thesis, University of New South Wales Australia.
Corsale K (1978) *Factors Affecting Children's Use of Organization in Recall.* PhD Thesis, University of North Carolina at Chapel Hill, Chapel Hill, NC.
Corsale K and Ornstein PA (1980) Developmental changes in children's use of semantic information in recall. *J. Exp. Child Psychol.* 30: 231–245.
Courage M and Cowan N (in press) *The Development of Memory in Childhood,* 2nd edn. Hove: Psychology Press.
Courage ML and Howe ML (2004) Advances in early memory development research: Insights about the dark side of the moon. *Dev. Rev.* 24: 6–32.
Darwin C (1877) A biographical sketch of an infant. *Mind* 2: 285–294.
DeCasper AJ and Spence MJ (1986) Prenatal maternal speech influences newborn's perception of speech sounds. *Infant Behav. Dev.* 9: 133–150.

DeLoache JS, Cassidy DJ, and Brown AL (1985) Precursors of mnemonic strategies in very young children's memory. *Child Dev.* 56: 125–137.

Eichenbaum H (2003) Learning and memory: Brain systems. In: Squire LR, Bloom FE, McConnell SK, Roberts JL, Spitzer NC, and Zigmond MJ (eds.) *Fundamental Neuroscience,* 2nd edn., pp. 1299–1327. San Diego: Academic Press.

Farrant K and Reese E (2000) Maternal style and children's participation in reminiscing: Stepping stones in children's autobiographical memory development. *J. Cogn. Dev.* 1: 193–225.

Farrar MJ and Goodman GS (1990) Developmental differences in the relation between scripts and episodic memory. In: Fivush RF and Hudson JA (eds.) *Knowing and Remembering in Young Children*, pp. 30–64. Cambridge: Cambridge University Press.

Fivush R (1984) Learning about school: The development of kindergartner's school script. *Child Dev.* 55: 1697–1709.

Fivush R (1991) The social construction of personal narratives. *Merrill-Palmer Q.* 37: 59–81.

Fivush R and Haden CA (1997) Narrating and representing experience: Preschooler's developing autobiographical recounts. In: van den Broek P, Bauer PJ, and Bourg T (eds.) *Developmental Spans in Event Comprehension and Representation: Bridging Fictional and Actual Events*, pp. 169–198. Mahwah, NJ: Erlbaum.

Fivush R, Haden C, and Adam S (1995) Structure and coherence of preschoolers' personal narratives over time: Implication for childhood amnesia. *J. Exp. Child Psychol.* 60: 32–56.

Fivush R and Hamond NR (1990) Autobiographical memory across the preschool years: Toward reconceptualizing childhood amnesia. In: Fivush R and Hudson JA (eds.) *Knowing and Remembering in Young Children*, pp. 223–248. Cambridge: Cambridge University Press.

Fivush R, Kuebli J, and Clubb PA (1992) The structure of events and event representations: A developmental analysis. *Child Dev.* 63: 188–201.

Fivush R, Reese E, and Haden CA (2006) Elaborating on elaborations: Role of maternal reminiscing style in cognitive and socioemotional development. *Child Dev.* 77: 1568–1588.

Fivush R and Slackman E (1986) The acquisition and development of scripts. In: Nelson K (ed.) *Event Knowledge: Structure and Function in Development*, pp. 71–96. Hillsdale, NJ: Erlbaum.

Fivush R and Vasudeva A (2002) Remembering to relate: Socioemotional correlates of mother-child reminiscing. *J. Cogn. Dev.* 3: 73–90.

Flannagan D, Baker-Ward L, and Graham L (1995) Talk about preschool: Patterns of topic discussion and elaboration related to gender and ethnicity. *Sex Roles* 32: 1–15.

Flavell JH (1970) Developmental studies of mediated memory. In: Reese HW and Lipsitt L (eds.) *Advances in Child Development and Behavior,* vol. 5, pp. 217–247. New York: Academic Press.

Flavell JH, Beach DR, and Chinsky JM (1966) Spontaneous verbal rehearsal in a memory task as a function of age. *Child Dev.* 37: 283–299.

Flavell JH and Wellman HM (1977) Metamemory. In: Kail RV and Hagan JW (eds.) *Perspectives on the Development of Memory and Cognition*, pp. 3–33. Hillsdale, NJ: Erlbaum.

Folds TH, Footo MM, Guttentag RE, and Ornstein PA (1990) When children mean to remember: Issues of context specificity, strategy effectiveness, and intentionality in the development of memory. In: Bjorklund DF (ed.) *Children's Strategies: Contemporary Views of Cognitive Development*, pp. 67–91. Hillsdale, NJ: Erlbaum.

Freud S (1914/1901) *The Psychopathology of Everyday Life*. London: T Fisher Unwin.

Goodman GS, Rudy L, Bottoms BL, and Aman C (1990) Children's concerns and memory: Issues of ecological validity in the study of children's eyewitness testimony. In: Fivush R and Hudson JA (eds.) *Knowing and Remembering in Young Children*, pp. 249–284. Cambridge: Cambridge University Press.

Goodman GS, Quas JA, Batterman-Faunce JM, Riddlesberger MM, and Kuhn J (1997) Children's reactions to and memory for a stressful event: Influences of age, anatomical dolls, knowledge, and parental attachment. *Appl. Dev. Sci.* 1: 54–74.

Greenhoot AF (2000) Remembering and understanding: The effects of changes in underlying knowledge on children's recollections. *Child Dev.* 71: 1309–1328.

Guttentag RE (1984) The mental effort requirement of cumulative rehearsal: A developmental study. *J. Exp. Child Psychol.* 37: 92–106.

Guttentag RE, Ornstein PA, and Siemens L (1987) Spontaneous rehearsal: Transitions in strategy acquisition. *Cogn. Dev.* 2: 307–326.

Haden CA (1998) Reminiscing with different children: Relating maternal stylistic consistency and sibling similarity in talk about the past. *Dev. Psychol.* 34: 99–114.

Haden C, Haine R, and Fivush R (1997) Developing narrative structure in parent-child conversations about the past. *Dev. Psychol.* 33: 295–307.

Haden CA, Ornstein PA, Eckerman CO, and Didow SM (2001) Mother-child conversational interactions as events unfold: Linkages to subsequent remembering. *Child Dev.* 72: 1016–1031.

Harley K and Reese E (1999) Origins of autobiographical memory. *Dev. Psychol.* 35: 1338–1348.

Hartshorn K, Rovee-Collier C, Gerhardstein P, et al. (1998) The ontogeny of long-term memory over the first year-and-a-half of life. *Dev. Psychobiol.* 32: 69–89.

Hayne H, Greco C, Earley L, Griesler P, and Rovee-Collier C (1986) Ontogeny of early event memory: II. Encoding and retrieval and 2- and 3-month olds. *Infant Behav. Dev.* 9: 461–472.

Hayne H, Barr R, and Herbert J (2003) The effect of prior practice on memory reactivation and generalization. *Child Dev.* 74: 1615–1627.

Hedrick AM (2006) *Elaborative Talk During and After Events: The Influence of Conversational Style on Event Memory.* PhD Thesis, Loyola University Chicago, Chicago, IL.

Herbert JH, Eckerman CO, and Stanton ME (2003) The ontogeny of human learning in delay, long-delay, and trace eyeblink conditioning. *Behav. Neurosci.* 117: 1196–1210.

Hill WL, Borovsky D, and Rovee-Collier C (1988) Continuities in infant memory development. *Dev. Psychobiol* 21: 43–62.

Howe ML and Courage LL (1997) The emergence and early development of autobiographical memory. *Psychol. Rev.* 104: 499–523.

Hudson JA (1990) The emergence of autobiographic memory in mother-child conversation. In: Fivush R and Hudson JA (eds.) *Knowing and Remembering in Young Children*, pp. 166–196. Cambridge: Cambridge University Press.

Hudson JA (2002) Do you know what we're going to do this summer? Mothers' talk to preschool children about future events. *J. Cogn. Dev.* 3: 49–71.

Hunter WS (1913) The delayed reaction in animals and children. *Anim. Behav. Monogr.* 2: 1–86.

Ivkovich D, Collins KL, Eckerman CO, Krasnegor CO, and Stanton ME (1999) Classical delay eyeblink conditioning in 4- and 5-month-old human infants. *Psychol. Sci.* 10: 4–8.

Kail R (1991) Developmental changes in speed of processing during childhood and adolescence. *Psychol. Bull.* 109: 490–501.

Kail RV and Hagen JW (1977) *Perspectives on the Development of Memory and Cognition*. Hillsdale, NJ: Erlbaum.

Kee DW and Davies L (1988) Mental effort and elaboration: A developmental analysis. *Contemp. Educ. Psychol.* 13: 221–228.

Kruse A, Lindenberger U, and Baltes PB (1993) Longitudinal research on human aging: The power of combining real-time, microgenetic, and simulation approaches. In: Magnusson D and Casaer PJM (eds.) *Longitudinal Research on Individual Development: Present Status and Future Perspectives*, pp. 153–193. Cambridge: Cambridge University Press.

Kuhn D (1995) Microgenetic study of change: What has it told us? *Psychol. Sci.* 6: 133–139.

Lange G (1978) Organization-related processes in children's recall. In: Ornstein PA (ed.) *Memory Development in Children*, pp. 101–128. Hillsdale, NJ: Erlbaum.

Lange G and Carroll DE (2003) Mother-child conversation styles and children's laboratory memory for narrative and nonnarrative details. *J. Cogn. Dev.* 4: 435–457.

Lehmann M and Hasselhorn M (2007) Variable memory strategy use in children's adaptive intratask learning behavior: Developmental changes and working memory influences in free recall. *Child Dev.* 78: 1068–1082.

Leichtman MD (2006) Cultural and maturational influences on long-term event memory. In: Balter L and Tamis-LeMonda CS (eds.) *Child Psychology: A Handbook of Contemporary Issues,* 2nd edn., pp. 569–589. Hove: Psychology Press.

Leichtman MD, Pillemer DB, Wang Q, Koreishi A, and Han JJ (2000) When Baby Maisy came to school: Mothers' interview styles and preschoolers' event memories. *Cogn. Dev.* 15: 99–114.

Liberty C and Ornstein PA (1973) Age differences in organization and recall: The effects of training in categorization. *J. Exp. Child Psychol.* 15: 169–186.

Low J and Durkin K (2001) Individual differences and consistency in maternal talk style during joint story encoding and retrospection: Associations with children's long-term recall. *Int. J. Behav. Dev.* 25: 27–36.

Mandler JM (1990) Recall of events by preverbal children. *Ann. NY Acad. Sci.* 608: 485–503.

Mandler JM (1998) Representation. In: Damon W (ed.) *Handbook of Child Psychology: Cognition, Perception, and Language,* vol. 2, pp. 255–308. New York: Wiley.

McCabe A and Peterson C (1991) Getting the story: A longitudinal study of parental styles in eliciting narratives and developing narrative skill. In: McCabe A and Pterson C (eds.) *Developing Narrative Structure*, pp. 217–253. Hillsdale, NJ: Erlbaum.

McDonough L, Mandler JM, McKee RD, and Squire LR (1995) Deferred imitation task as a nonverbal measure of declarative memory. *Proc. Natl. Acad. Sci. USA* 92: 7580–7584.

McGuigan F and Salmon K (2004) The time to talk: The influence of the timing of adult-child talk on children's event memory. *Child Dev.* 75: 669–686.

McGuigan F and Salmon K (2005) Pre-event discussion and recall of a novel event: How are children best prepared? *J. Exp. Child Psychol.* 91: 342–366.

Meltzoff AN (1985a) Immediate and deferred imitation in fourteen and twenty-four-month-old infants. *Child Dev.* 56: 62–72.

Meltzoff AN (1988) Infant imitation after a 1-week delay: Long-term memory for novel acts and multiple stimuli. *Dev. Psychol.* 24: 470–476.

Meltzoff AN (1988b) Infant imitation and memory: Nine-month-olds in immediate and deferred tests. *Child Dev.* 59: 217–225.

Meltzoff AN (1995) What infant memory tells us about infantile amnesia: Long-term recall and deferred imitation. *J. Exp. Child Psychol.* 59: 497–515.

Merritt KA, Ornstein PA, and Spicker B (1994) Children's memory for a salient medical procedure: Implications for testimony. *Pediatrics* 94: 17–22.

Miller PH (1990) The development of strategies of selective attention. In: Bjorklund DF (ed.) *Children's Strategies: Contemporary Views of Cognitive Development*, pp. 157–184. Mahwah, NJ: Erlbaum.

Moely BE, Hart SS, Leal L, et al. (1992) The teacher's role in facilitating memory and study strategy development in the elementary school classroom. *Child Dev.* 63: 653–672.

Morrison FJ, Smith L, and Dow-Ehrensberger M (1995) Education and cognitive development: A natural experiment. *Dev. Psychol.* 31: 789–799.

Moscovitch M (2000) Theories of memory and consciousness. In: Tulving E and Craik FIM (eds.) *The Oxford Handbook of Memory*, pp. 609–625. Oxford: Oxford University Press.

Muir-Broaddus JE and Bjorklund DF (1990) Developmental and individual differences in children's memory strategies: The role of knowledge. In: Schneider W and Weinert FE (eds.) *Aptitudes, Strategies, and Knowledge in Cognitive Performance*, pp. 99–116. New York: Springer-Verlag.

Murachver T, Pipe M-E, Gordon R, Owens JL, and Fivush R (1996) Do, show, and tell: Children's event memories acquired through direct experience, observation, and stories. *Child Dev.* 67: 3029–3044.

Myers N and Perlmutter M (1978) Memory in the years from two to five. In: Ornstein PA (ed.) *Memory Development in Children*, pp. 191–218. Hillsdale, NJ: Erlbaum.

Nelson CA (1995) The ontogeny of human memory: a cognitive neuroscience perspective. *Dev. Psychol.* 31: 723–738.

Nelson K (1978) How children represent knowledge of their world in and out of language: A preliminary report. In: Seigler RS (ed.) *Children's Thinking: What Develops?* pp. 255–273. Hillsdale, NJ: Erlbaum.

Nelson K (1986) *Event knowledge: Structure and Function in Development*. Hillsdale, NJ: Erlbaum.

Nelson K, Fivush R, Hudson JA, and Lucariello J (1983) Scripts and the development of memory. In: Chi MTH (ed.) *Contributions to Human Development, vol. 9. Trends in Memory Development Research*, pp. 52–70. Basel: Kargar.

Nelson K and Gruendel J (1979) At morning it's lunchtime: A scriptal view of children's dialogues. *Discourse Process* 2: 73–94.

Nelson KA and Gruendel J (1981) Generalized event representations: Basic building blocks of cognitive development. In: Lamb ME and Brown AL (eds.) *Advances in Developmental Psychology, vol. 1. Contributions to Human Development*, pp. 131–158. Hillsdale, NJ: Erlbaum.

Oakes LM and Bauer PJ (2007) *Short and Long-Term Memory in Infancy and Early Childhood*. New York: Oxford University Press.

Ornstein PA (1995) Children's long term retention of salient personal experiences. *J. Trauma. Stress* 8: 581–605.

Ornstein PA, Baker-Ward L, Gordon BN, and Merritt KA (1997a) Children's memory for medical experiences. *Appl. Cogn. Psychol.* 11: S87–S104.

Ornstein PA, Baker-Ward L, Gordon BN, Pelphrey KA, Tyler CS, and Gramzow E (2006a) The influence of prior knowledge and repeated questioning on children's long-term retention of the details of a pediatric examination. *Dev. Psychol.* 42: 332–344.

Ornstein PA, Baker-Ward L, and Naus MJ (1988) The development of mnemonic skill. In: Weinert FE and Perlmutter M (eds.) *Memory Development: Universal Changes and Individual Differences*, pp. 31–50. Hillsdale, NJ: Erlbaum.

Ornstein PA, Coffman JL, McCall LE, Grammer JK, and San Souci P (in press) Linking the classroom context and the development of children's memory skills. In: Meece J and Eccles J (eds.) *Handbook of Research on Schools, Schooling, and Human Development.* Mahwah, NJ: Erlbaum.

Ornstein PA and Haden CA (2001) Memory development or the development of memory? *Curr. Dir. Psychol. Sci.* 6: 202–205.
Ornstein PA, Haden CA, and Elischberger HB (2006b) Children's memory development: Remembering the past and preparing for the future. In: Bialystok E and Craik FIM (eds.) *Lifespan Cognition: Mechanisms of Change*, pp. 143–161. Oxford: Oxford University Press.
Ornstein PA, Haden CA, and Hedrick AM (2004) Learning to remember: Social-communicative exchanges and the development of children's memory skills. *Dev. Rev.* 24: 374–395.
Ornstein PA, Medlin RG, Stone BP, and Naus MJ (1985) Retrieving for rehearsal: An analysis of active research in children's memory. *Dev. Psychol.* 21: 633–641.
Ornstein PA, Merritt KA, Baker-Ward L, Furtado E, Gordon BN, and Principe G (1998) Children's knowledge, expectation, and long-term retention. *Appl. Cogn. Psychol.* 12: 387–405.
Ornstein PA and Myers JT (1996) Contextual influences on children's remembering. In: Pezdek K and Banks WP (eds.) *The Recovered Memory/False Memory Debate*, pp. 211–223. San Diego: Academic Press.
Ornstein PA and Naus MJ (1978) Rehearsal processes in children's memory. In: Ornstein PA (ed.) *Memory Development in Children*, pp. 69–99. Hillsdale, NJ: Erlbaum.
Ornstein PA and Naus MJ (1985) Effects of the knowledge base on children's memory strategies. In: Reese HW (ed.) *Advances in Child Development and Behavior,* vol. 19, pp. 113–148. New York: Academic Press.
Ornstein PA, Naus MJ, and Liberty C (1975) Rehearsal and organizational processes in children's memory. *Child Dev.* 26: 818–830.
Ornstein PA, Naus MJ, and Stone BP (1977) Rehearsal training and developmental differences in memory. *Dev. Psychol.* 13: 15–24.
Ornstein PA, Shapiro LR, Clubb PA, Follmer A, and Baker-Ward L (1997b) The influence of prior knowledge on children's memory for salient medical experiences. In: Stein N, Ornstein PA, Tversky B, and Brainerd CJ (eds.) *Memory for Everyday and Emotional Events*, pp. 83–112. Mahwah, NJ: Erlbaum.
Ornstein PA, Trabasso T, and Johnson-Laird PN (1974) To organize is to remember: The effects of instructions to organize and recall. *J. Exp. Psychol.* 103: 1014–1018.
Paris SG, Newman RS, and McVey KA (1982) Learning the functional significance of mnemonic actions: A microgenetic study of strategy acquisition. *J. Exp. Child Psychol.* 34: 490–509.
Pascalis O, de Haan M, Nelson CA, and de Schonen S (1998) Long-term recognition memory for faces assessed by visual paired comparison in 3- and 6-month-old infants. *J. Exp. Psychol. Learn. Mem. Cogn.* 24: 249–260.
Peterson C and Bell M (1996) Children's memory for traumatic injury. *Child Dev.* 67: 3045–3070.
Peterson C, Jesso B, and McCabe A (1999) Encouraging narratives in preschoolers: An intervention study. *J. Child Lang.* 26: 49–67.
Pressley M, Borkowski JG, and Schneider W (1989) Good information processing: What it is and what education can do to promote it. *Int. J. Educ. Res.* 13: 857–867.
Preyer W (1889) *The Mind of the Child*. New York: Appleton.
Principe G, Myers JT, Furtado E, Merritt K, and Ornstein PA (1996) The relationship between procedural information and young children's recall of an invasive medical procedure. In: Baker-Ward L (chair) *The Role of Individual Differences in Young Children's Reports of Salient Personal Experiences*. Paper presented at the Conference on Human Development, Birmingham, AL, July 2005.
Principe GF, Ornstein PA, Baker-Ward L, and Gordon BN (2000) The effects of intervening experiences on children's memory for a physical examination. *Appl. Cogn. Psychol.* 14: 59–80.
Rabinowitz M and McAuley R (1990) Conceptual knowledge processing: An oxymoron. In: Schneider W and Weinert FE (eds.) *Interactions Among Aptitudes, Strategies, and Knowledge in Cognitive Performance*, pp. 117–133. New York: Springer-Verlag.
Ratner HH, Smith BS, and Padgett RJ (1990) Children's organization of events and event memories. In: Fivush R and Hudson JA (eds.) *Knowing and Remembering in Young Children*, pp. 65–93. Cambridge: Cambridge University Press.
Reese E, Haden CA, and Fivush R (1993) Mother-child conversations about the past: Relationships of style and memory over time. *Cogn. Dev.* 8: 403–430.
Roebers CM and Schneider W (2001) Individual differences in children's eyewitness recall: The influence of intelligence and shyness. *Appl. Dev. Sci.* 5: 9–20.
Rogoff B (1981) Schooling's influence on memory test performance. *Child Dev.* 52: 260–267.
Rose SA, Gottfried AW, Melloy-Carminar P, and Bridger WH (1982) Familiarity and novelty preferences in infant recognition memory: Implications for information processing. *Dev. Psychol.* 18: 704–713.
Ross M (1989) Relation of implicit theories to the construction of personal histories. *Psychol. Rev.* 96: 341–357.
Rovee-Collier C (1995) Time windows in cognitive development. *Dev. Psychol.* 31: 147–169.
Rovee-Collier C (1997) Dissociations in infant memory: Rethinking the development of implicit and explicit memory. *Psychol. Rev.* 104: 467–498.
Rovee-Collier C and Hayne H (1987) Reactivation of infant memory: Implications for cognitive development. In: Reese HW (ed.) *Advances in Child Development and Behavior,* vol. 20, pp. 185–238. New York: Academic Press.
Rovee-Collier C, Hayne H, and Columbo M (2001) *The Development of Implicit and Explicit Memory*. Amsterdam: John Benjamins.
Rovee-Collier C, Schechter A, Shyi G, and Shields P (1992) Perceptual identification of contextual attributes and infant memory retrieval. *Dev. Psychol.* 28: 307–318.
Rovee-Collier C and Shyi CWG (1992) A functional and cognitive analysis of infant long-term memory. In: Howe M, Brainerd C, and Reyna VF (eds.) *Development of Long-Term Retention*, pp. 3–55. New York: Springer-Verlag.
Rovee-Collier CK, Sullivan MW, Enright M, Lucas D, and Fagen JW (1987) Reactivation of infant memory. In: Oates J and Sheldon S (eds.) *Cognitive Development in Infancy*, pp. 87–92. Hove: Erlbaum.
Schacter DL (1987) Implicit memory: History and current status. *J. Exp. Psychol. Learn. Mem. Cogn.* 13: 501–518.
Schlagmüller M and Schneider W (2002) The development of organizational strategies in children: Evidence from a microgenetic longitudinal study. *J. Exp. Child Psychol.* 81: 298–319.
Schneider W (1985) Developmental trends in the metamemory-memory relationship: An integrative review. In: Forrest-Pressley DL, MacKinnon GE, and Waller TG (eds.) *Metacognition, Cognition, and Human Performance,* vol. 1, pp. 57–109. New York: Academic Press.
Schneider W and Bjorklund DF (1998) Memory. In: Kuhn D and Siegler R (eds.), *Handbook of Child Psychology: Cognition, Perception, and Language,* vol. 2, 5th edn., pp. 467–521. Hoboken, NJ: Wiley.
Schneider W, Körkel J, and Weinert FE (1989) Domain-specific knowledge and memory performance: A comparison of high- and low-aptitude children. *J. Educ. Psychol.* 81: 306–312.

Schneider W, Kron V, and Hünnerkoph M (2004) The development of young children's memory strategies. First findings from the Würzburg longitudinal Memory Study. *J. Exp. Child Psychol.* 88: 193–209.
Schneider W and Pressley M (1997) *Memory Development Between Two and Twenty*, 2nd edn. Mahwah, NJ: Erlbaum.
Schneider W, Schlagmüller M, and Vise M (1998) The impact of metamemory and domain-specific knowledge on memory performance. *Eur. J. Psychol. Educ.* 13: 91–103.
Scribner S and Cole M (1978) Literacy without schooling: Testing for intellectual effects. *Harvard Educ. Rev.* 48: 448–461.
Siegler RS (1996) *Emerging Minds: The Process of Change in Children's Thinking*. Oxford: Oxford University Press.
Siegler RS (2006) Microgenetic analyses of learning. In: Kuhn D, Siegler RS, Damon W, and Lerner RM (eds.) *Handbook of Child Psychology, vol. 2, Cognition, Perception, and Language,* 6th edn., pp. 464–510. Hobokon, NJ: Wiley.
Siegler RS and Crowley K (1991) The microgenetic method: A direct means for studying cognitive development. *Am. Psychol.* 46: 606–620.
Siegler RS and Crowley K (1994) Constraints on learning in nonprivileged domains. *Cogn. Psychol.* 27: 194–227.
Siegler RS and Jenkins EA (1989) *How Children Discover New Strategies*. Hillsdale, NJ: Erlbaum.
Slackman EA and Nelson K (1984) Acquisition of an unfamiliar script in story form by young children. *Child Dev.* 55: 329–340.
Slater A, Morison V, and Rose D (1984) Habituation in the newborn. *Infant Behav. Dev.* 7: 183–200.
Sodian B and Schneider W (1999) Memory strategy development: Gradual increase, sudden insight, or roller-coaster? In: Weinert FE and Schneider W (eds.) *Individual Development from 3 to 12: Findings from the Munich Longitudinal Study*, pp. 61–77. Cambridge: Cambridge University Press.
Sodian B, Schneider W, and Perlmutter M (1986) Recall, clustering, and metamemory in young children. *J. Exp. Child Psychol.* 41: 395–410.
Spear NE and Parsons PJ (1976) Analysis of a reactivation treatment: Ontogenetic determinants of alleviated forgetting. In: Medin DL, Roberts WA, and Davis RT (eds.) *Processes of Animal Memory*, pp. 135–165. Hillsdale, NJ: Erlbaum.
Squire L (1987) *Memory and Brain*. Oxford: Oxford University Press.
Stern C and Stern W (1909) *Erinnerung Aussage und Lüge*. Lipzeig: Barth.
Sullivan MW (1982) Reactivation: Priming forgotten memories in human infants. *Child Dev.* 53: 516–523.
Sweeney B and Rovee-Collier C (2001) The minimum duration of reactivation at 6 months: Latency of retrieval and reforgetting. *Infant Behav. Devel.* 24: 259–280.
Tarkin B (1981) *The Effects of Stimulus Meaningfulness on Children's Spontaneous Rehearsal Strategies.* Senior Honors Thesis, University of Massachusetts.
Terman LM (1916) *The Measurement of Intelligence: An Explanation of and a Complete Guide for the Use of the Stanford Revision and Extension of the Binet-Simon Intelligence Scale*. New York: Houghton Miflin.
Terman LM and Merrill MA (1937) *Measuring Intelligence: A Guide to the Administration of the New Revised Stanford-Binet Tests of Intelligence*. New York: Houghton-Miflin.
Tessler M and Nelson K (1994) Making memories: The influence of joint encoding on later recall by young children. *Conscious. Cogn.* 3: 307–326.
Wagner DA (1978) Memories of Morocco: The influence of age, schooling, and environment on memory. *Cogn. Psychol.* 10: 1–28.
Wechsler D (1939) *The Measurement of Adult Intelligence*. Baltimore: Williams and Wilkins.
Welch-Ross MK (1997) Mother-child participation in conversation about the past: Relationship to preschoolers' theory of mind. *Dev. Psychol.* 33: 618–629.
Welch-Ross MK (2001) Personalizing the temporally extended self: Evaluative self-awareness and the development of autobiographical memory. In: Moore C and Skene K (eds.) *The Self in Time: Developmental Issues*, pp. 97–120. Mahwah, NJ: Erlbaum.
Wellman HM (1988) The early development of memory strategies. In: Weinert FE and Perlmutter M (eds.) *Memory Development: Universal Changes and Individual Differences*, pp. 3–29. Hillsdale, NJ: Erlbaum.

# 2.38 Developmental Disorders of Learning*

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## 2.38.1 Developmental Disorders of Learning: What Do They Actually Mean?

Phenomenologically, the category of developmental disorders of learning refers to children who, for one reason or another, differ from their peers in acquisition of developmentally appropriate skills (e.g., speaking, counting, reading).

Conceptually, the category of developmental disorders of learning refers to deviations from typical development (1) that are substantial enough to qualify as disorders and (2) that affect learning. However, there is no single nosological category that brings these disorders together, and the two most established diagnostic manuals, the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV, published by the American Psychiatric Association, 1994) and the *International Classification of Diseases and Related Health Problems* (IDC-10, published by the World Health Organization, 2005), present only a partial overlap in how these disorders are classified.

The diversity of the disorders commonly viewed as developmental disorders of learning is captured in the following paragraphs. This list is presented here not to overwhelm the reader (and the information is quite daunting!), but rather to demonstrate a lack of agreement of what disorders of learning actually are.

Specifically, DSM-IV distinguishes a large category of Disorders Usually First Diagnosed in Infancy, Childhood, or Adolescence. This category includes, among other subcategories, the disorders that directly involve and affect learning, specifically, Mental Retardation; Learning Disorders (Reading Disorder, Mathematics Disorder, Disorder of Written Expression, and Learning Disorder Not Otherwise Specified, NOS); Motor Skills Disorders; Communication Disorders (Expressive Language Disorder, Mixed Receptive-Expressive Language Disorder, Phonological Disorder, Stuttering, and Communication Disorder NOS); Pervasive Developmental Disorders (Autistic Disorder, Rett's Disorder, Childhood Disintegrative Disorder, Asperger's Disorder, and Pervasive Developmental Disorder NOS); and Attention-Deficit and Disruptive Behavior Disorders (Attention-Deficit/Hyperactivity Disorder (ADHD), Conduct Disorder, Oppositional Defiant Disorder, and Disorders in Both Categories NOS).

ICD-10's Chapter V presents Mental and Behavioural Disorders with subcategories referred to as (1) Disorders of Psychological Development and (2) Mental and Behavioural Disorders. The former category is subdivided into Specific Developmental

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Disorder of Speech and Language (Specific Speech Articulation Disorder, Expressive Language Disorder, Receptive Language Disorder, Acquired Aphasia with Epilepsy, Other Developmental Disorders of Speech and Language, and Developmental Disorder of Speech and Language, Unspecified); Specific Developmental Disorders of Scholastic Skills (Specific Reading Disorder, Specific Spelling Disorder, Specific Disorder of Arithmetic Skills, Mixed Disorder of Scholastic Skills, Other Developmental Disorder of Scholastic Skills, Developmental Disorder of Scholastic Skills, Unspecified); Specific Developmental Disorder of Motor Function; Mixed Specific Developmental Disorders; Pervasive Developmental Disorders (Pervasive Developmental Disorders, Childhood Autism, Atypical Autism, Rett's Syndrome, Other Childhood Disintegrative Disorder, Overactive Disorder Associated with Mental Retardation and Stereotyped Movements, Asperger's Syndrome, Other Pervasive Developmental Disorders, Pervasive Developmental Disorder, Unspecified), among other disorders. The latter category includes a cluster of disorders associated with hyperactivity and conduct problems (e.g., Hyperkinetic Disorder and Conduct Disorder), separating attention problems from problems of hyperactivity (with attention problems listed in the first category as a psychological problem) and including stuttering in this category, rather than as a disorder of speech and language.

To restate, there is no uniformly accepted approach in how developmental disorders of learning should be referred to or classified. Correspondingly, in staging the discussion that unfolds in this chapter, it is important to comment on the following three issues. First, it is clear that no single nosological category captures all developmental disorders of learning. There are many developmental disorders where learning is disrupted. Second, many of these developmental disorders are comorbid, that is, co-occur in the same individual. Thus, which disorder is diagnosed as primary and what other disorders are codiagnosed is variable. Third, although there are many disorders in which learning is disrupted, the 'label' that typically denotes challenged learning is Learning Disability (LD). As mentioned earlier, this category is not used as a diagnostic category. Yet, there is a mountain (or rather a mountain chain) of literature on this category. For the ensuing discussion, it is important to differentiate nonspecific (or general) and specific LDs. Conventionally, the term nonspecific LD is used to refer to generalized problems of learning, such as mental retardation, and the term specific LD (SLD) is used to refer to disorders in a particular domain of acquisition or learning, such as reading, writing, or mathematics.

In this chapter, I use the concept of LD even though, as mentioned earlier, it does not correspond directly to any particular nosological category in the two predominant diagnostic schemes of the developed world. Throughout the chapter, I argue that LD best captures the common thread of all developmental disorders of learning.

## 2.38.2 The Concept of Learning Disabilities

Fundamentally, the concept of LD encompasses society's capacity

> . . . to monitor (and recruit) children for unexplained school failure in a way that was not possible before the LD category was reified and passed into law in 1969. (Reid and Valle, 2004: 467)

The LD category replaced a variety of 'loose' definitional references to previously used qualifiers such as 'slow learner,' 'backward children' (Franklin, 1987), and 'minimal brain dysfunction' (Fletcher et al., 2002).

In terms of its 'realization' in the context of current practices, the LD label typically assumes the presence of the following process. Under normal circumstances, LDs are not diagnosable prior to a child's engagement with schooling and the opportunity to master key academic competencies. While in school, a child is assumed to be assigned grade-appropriate tasks. These tasks assume some degree of variability in children's performance; these theoretical ranges constrain the definitions of acceptable and worrisome variability in performance (*See* Chapter 2.40). It is when the child's performance consistently falls out of the acceptable range in one or more academic subjects that the child becomes the focus of intense observation and documentation and is referred for evaluation to appropriate professionals (e.g., educational psychologists, neuropsychologists, and clinicians such as pediatricians, clinical psychologists, or psychiatrists). An important qualifier here is that such observation, documentation, and evaluation are considered only for children whose performance is below that expected based on their general capacity to learn; thus, the concept of 'unexpected' school failure is central to the definition of LD. When reports on the child's performance in the classroom, testing results, and clinical evaluations are compiled, the child and his or her family are referred to a special education committee, which determines eligibility for individualized special education services. If eligibility is established, an Individualized Education Program (IEP) is created. The IEP refers to a specific diagnostic label carried by the child and cites the proper category of public laws that guarantees services for an individual with such a diagnosis.

## 2.38.3 Definition

The definition that currently drives federal regulations was produced by the National Advisory Committee on Handicapped Children in 1968 and subsequently adopted by the U.S. Office of Education in 1977 (Mercer et al., 1996). According to this definition,

> Specific learning disability means a disorder in one or more of the basic psychological processes involved in understanding or in using language, spoken or written, which may manifest itself in an imperfect ability to listen, think, speak, read, write, spell, or to do mathematical calculations. The term includes such conditions as perceptual handicaps, brain injury, minimal brain dysfunction, dyslexia, and developmental aphasia. The term does not include children who have learning problems which are primarily the result of visual, hearing, or motor handicaps, of mental retardation, or emotional disturbance, or of environmental, cultural, or economic disadvantage. (U.S. Office of Education, 1977: 65083)

Again, neither DSM-IV nor ICD-10 uses the term learning disabilities. DSM-IV makes a reference to learning disorders (American Psychiatric Association, 1994), which, according to DSM-IV, can be diagnosed,

> . . .when the individual's achievement on individually administered, standardized tests in reading, mathematics, or written expression is substantially below that expected for age, schooling, and level of intelligence. (American Psychiatric Association, 1994: 46)

Of interest here is that this is one of the very few categories of DSM-IV where a reference is made explicitly to psychological tests, although DSM-IV does not provide specific guidelines as to what 'substantially below' means. Thus, DSM-IV implicitly refers to evidence-based practices (Fletcher et al., 2002) in the field. The problem, of course, is that there are multiple interpretations of these best practices (see discussion to follow). Yet, assuming there are consistent and coherent guidelines in place for establishing a diagnosis of LD, DSM-IV classifies types of LDs by referencing the primary academic areas of difficulty. The classification includes three specific categories and a residual diagnosis: Reading Disorder, Mathematics Disorder, Disorder of Written Expression, and Learning Disorder NOS. A common practice in the field is to view a diagnosis of a learning disorder as established by DSM-IV as an equivalent to 'specific learning disability,' which qualifies a child for special services under federal regulations (House, 2002).

## 2.38.4 History

The introduction of the concept of LD is typically credited to Samuel Kirk (then a professor of special education at the University of Illinois), who, while presenting at a parent meeting in Chicago on April 6, 1963, proposed the term learning disabled to refer to "children who have disorders in development of language, speech, reading, and associated communication skills" (Strydom and du Plessis, 2000). The category was well received by parents and promoted shortly thereafter by an established parent advocacy group known as the Association for Children with Learning Disabilities. Prior to the formal introduction of this concept, the literature had accumulated numerous descriptions of isolated cases and group analyses of children with specific deficits in isolated domains of academic performance (e.g., reading and math) whose profiles were later reinterpreted as those of individuals with specific LDs (e.g., specific reading and math disabilities). It is those examples in the literature and the experiences of many distressed parents who could not find adequate educational support for their struggling children that, in part, resulted in the creation of the field of LDs as a social reality and professional practice (Hallahan and Mercer, 2002). Subsequent accumulation of research evidence and experiential pressure led to the formulation of legislation protecting the rights of children with LDs.

Congress enacted the Education for All Handicapped Children Act (Public Law 94-142) in 1975 to support states and educational institutions in protecting the rights of, meeting the individual needs of, and improving the results of schooling for infants, toddlers, children, and youth with disabilities and their families. This landmark law is currently enacted as the Individuals with Disabilities Education Act (IDEA, Public Law 105-17; although the precise title of the law in its 2004 amendment is Individuals with Disabilities Education Improvement Act, it is still referred to as IDEA), as amended in 2004. The importance of this law is difficult to overstate: In 1970, U.S. schools provided education to only one in five children with disabilities (U.S. Office of Special Education Programs, 2000). By 2003–2004, the number of children aged 3–21 served under IDEA was more than 6.6 million (National Center for Education Statistics, 2005b).

SLDs make up 50% of all special education students served under IDEA. The term has proliferated very successfully and very quickly within the last two decades. There are multiple reasons why the concept of LD has enjoyed such success, among which are a lack of social stigma (i.e., parents are much more comfortable with the label of LD than with categories such as minimal brain dysfunction or brain injury), absence of implication of low intelligence or behavioral problems, and access to services (Zigmond, 1993).

In its 2004 amendment, IDEA recognized 13 categories under which a child can be identified as having a disability: autism; deaf–blindness; deafness; emotional disturbance; hearing impairment; mental retardation; multiple disabilities; orthopedic impairment; other health impairment; specific learning disability; speech or language impairment; traumatic brain injury; and visual impairment including blindness. It is notable that LDs as described in IDEA are referred to as 'specific learning disabilities' to emphasize the difference between children with SLDs and those with general learning difficulties characteristic of other IDEA categories (e.g., autism and mental retardation). The consensus in the field is that children with LDs possess average to above-average levels of intelligence across many domains of functioning but demonstrate specific deficits within a narrow range of academic skills. Finally, as stated earlier, exclusionary factors have been central to diagnoses of LDs since the authoritative definition of LD was introduced in 1977. As per these exclusionary criteria, a child cannot be diagnosed with an LD unless factors such as other disorders or lack of exposure to high-quality age-, language-, and culture-appropriate educational environments have been ruled out. It is the desire to rule out the exclusionary factor of lack of exposure to high-quality environments that prompted the introduction of the concept of Response to Treatment Intervention (RTI) (Deshler et al., 2005) in the 2004 amendment of IDEA. RTI signifies

> . . . individual, comprehensive student-centered assessment models that apply a problem-solving framework to identify and address a student's learning difficulties. (Deshler et al., 2005: 483)

It is important to note that RTI might appear counterintuitive at first: How can a disorder be defined through treatment if treatment is prescribed for a particular disorder? This 'circularity' of RTI, however, is only superficial. An implicit assumption behind RTI is that teaching is inadequate, and that is why schools 'produce' such a high level of LDs. A closer analogy would not be with treatment, but with prevention with vitamins; if vitamins are delivered properly, then many deficiencies can be avoided. Thus, if all children get extensive preventive instruction, the frequencies of LDs will diminish (see more detail on RTI in the section titled 'Presentation and diagnoses').

## 2.38.5 Epidemiology

Since the 1968 statutory introduction of LD as a legislated disability (i.e., within ~35 years of its existence as a category), approximately 50% of all students receiving special educational services across the nation have received them under the category of LD (Donovan and Cross, 2002). Among these students, the majority (80–90%) demonstrate substantial difficulties in reading (Kavale and Reese, 1992), and two of every five were identified because of persistent difficulties in reading acquisition (President's Commission on Excellence in Special Education, 2002).

There are two main sources for estimates of prevalence rates of LDs.

The first and most obvious one is linked to the number of children served under this category of IDEA. When this number is mapped on the total number of school-age children in the United States, although the number fluctuates from year to year, the average estimates of prevalence rates for LDs are around 5–6% of the total school-age population. To illustrate, in 2003, 2.72 million children were identified as having LDs. This represents a 150–200% increase in the number of students aged 6–17 with LDs compared with that number in 1975.

Yet, it is important to note that prevalence rates vary substantially from district to district and from state to state. For example, in 2004, under the SLD category, in Kentucky, 1.8% of all students aged 6–21 received special education services, compared with 5.9% in Iowa. Thus, based on these numbers, the prevalence rates of LDs in Iowa are about 3.3 times as high as in Kentucky, two states in close geographic proximity! This observation stresses the mosaic-like situation of LD diagnosis – there is no unified approach to these diagnoses across different local education agencies in the United States.

When IDEA-related prevalence rates are considered, LDs are observed more frequently in boys than in girls (64.5% vs. 33.5% for boys and girls aged 6–17, respectively) and more frequently in underrepresented minority groups than in Asian Americans or Whites. Risk ratios (which compare the proportion of a particular racial/ethnic group served to the proportion of all other racial/ethnic groups combined) are 1.5, 0.4, 1.3, 1.1, and 0.9 for American Indian, Asian American, African American, Hispanic American, and White students, respectively. A risk ratio of 1.0 indicates no difference between the racial/ethnic groups.

The second source for these rates is research studies. Per results from these studies, it is assumed that, although 10–12% of school-age children show specific deficits in selected academic domains, high-quality classroom instruction and supplemental intensive small-group activities can reduce this number to ~6% of children. It is assumed that these 6% will meet strict criteria for LDs and require special education intervention.

It is important to note that most of the research in the field of LDs is currently conducted with reading and, correspondingly, Specific Reading Disability (SRD). There is little established evidence that reliably points to prevalence rates of disorders of math and writing.

To illustrate, according to the results of current research on early reading acquisition, 2–6% of children do not show expected progress even in the context of the highest quality evidence-based reading instructions. Based on U.S. national data, the risk for reading problems as defined through failure to reach age- and grade-adequate milestones ranges from 20–80%. Specifically, data from the 2005 National Assessment of Educational Progress show that 36% of fourth graders do not possess the adequate reading skills required for completion of grade-appropriate educational tasks (National Center for Education Statistics, 2005a). However, it is clear that far from all of these children have SRD. The majority of these children mostly likely underachieve because of inadequate educational experiences and causes other than SRD.

Some changes in the 2004 version of IDEA were invoked directly because of concerns regarding the overidentification of students as learning disabled. The category of LDs has often been the largest single category of children served under IDEA (for latest relevant statistics, see IDEA Data, 2006). The reality of everyday practices in school districts was such that most diagnoses prior to the 2004 reauthorization were based on so-called aptitude–achievement discrepancy criteria, which required a severe discrepancy between IQ and achievement scores (e.g., two standard deviations, 2 years of age equivalence), although IDEA had never specifically required a discrepancy formula (Mandlawitz, 2006). Correspondingly, it has been argued that these discrepancy-based approaches are flawed (Francis et al., 2005) and might have led to overidentification. In light of this hypothesis, IDEA 2004 emphasizes that there is no explicit IQ–achievement discrepancy requirement for diagnosis of LDs. As a possible alternative approach for identification and diagnosis, IDEA 2004 states that local educational agencies may use a child's RTI in lieu of classification processes (Council of Parent Attorneys and Advocates, 2004). A local educational agency (e.g., a school) may choose to administer to the child in question an evidence-based intervention program to determine his or her eligibility for special education services under IDEA based on the child's response to this program.

Specifically, the statutory language of IDEA 2004 (Public Law 108-446) states:

> (6) Specific Learning Disabilities.
>
> (A) In general.
>
> Notwithstanding section 607(b), when determining whether a child has a specific learning disability as defined in section 602, a local educational agency shall not be required to take into consideration whether a child has a severe discrepancy between achievement and intellectual ability in oral expression, listening comprehension, written expression,

basic reading skill, reading comprehension, mathematical calculation, or mathematical reasoning.
(B) Additional authority.
In determining whether a child has a specific learning disability, a local educational agency may use a process that determines if the child responds to scientific, research-based intervention as a part of the evaluation procedures described in paragraphs (2) and (3). (§614(b) (6))

As a consequence of this language, although aptitude–achievement discrepancy has been and continues to remain the common, although not required, practice for local educational agencies, there is a new 'entry point' for RTI. Needless to say, these changes are of great theoretical and practical importance. The tradition and system of specific LD identification in the United States are now fluid, and rather few specific recommendations exist to help local educational agencies smoothly transition into the implementation of IDEA 2004.

## 2.38.6 Presentation and Diagnoses

As stated earlier, it is crucially important in a diagnosis of LD to establish a child's 'typical' intellectual performance and to document that the child's performance in the area of difficulty (e.g., reading or mathematics) does not correspond to what would be expected, given average intellectual functioning. Although this general principle is relatively easy to grasp, the field of LDs has struggled since its inception in the early 1960s to establish specific steps that should lead to the establishment of the diagnosis.

Prior to the 2004 reauthorization of IDEA, the most common way of establishing an LD diagnosis was the discrepancy criterion. The introduction of the discrepancy between ability and achievement criteria in the 1977 law was not based on empirical research, but rather driven by a need for a more objective approach to the diagnoses than those commonly used and largely discredited at the time (Gresham et al., 2004). Two decades of research and practical explorations of the discrepancy model resulted in its discreditation from points of view of theory (Sternberg and Grigorenko, 2002), reliability of diagnosis and classification (Francis et al., 2005), robustness of implementation (Haight et al., 2002), and treatment validity (Aaron, 1997). In response to the overwhelming amount of evidence for the inadequacy of the discrepancy model, however realized (through psychometric indices, age equivalences, regression approaches, or expert opinions), a number of alternative models have been proposed. The major dividing line between these new models and previous discrepancy-based models is in their theoretical orientation. Previous diagnostic models attempted to identify children diagnosable with LDs by looking for characteristic cognitive deficits, so that an intervention could be delivered to children with such deficits (Reschly, 1996), whereas the modern models argue for the need to deliver best pedagogical practices to all children and then best remediational-intervention approaches to those children who do not respond as well to good teaching (Reschly and Ysseldyke, 2002).

As per the 2004 reauthorization of IDEA, local educational agencies have some choice in selecting diagnostic models. At this point, the most widely discussed and evidence-supported model of LD identification is the Responsiveness/Response to Intervention (RTI) model (Vaughn and Fuchs, 2003). The RTI model has a number of features. First, the performance of the student in question is compared with the performance of his/her immediate peers on academic tasks. Specifically, RTI assumes tracking the academic performance and rate of its growth for all students within a given class, with a goal of identifying those students in a class whose performance differs from that of their peers both in absolute (i.e., level) and relative (i.e., rate of growth) terms. Second, the model is structured primarily by intervention, so students identified by these means are offered individualized accommodations and interventions with a goal of maximizing the effectiveness of the learning environment for a given student in need. Third, the model is multilayered, so that each layer offers an opportunity for further differentiation and individualization of education for students who need it. Typically, three layers are recommended: The first tier covers regular classroom environment; the second tier is characterized as 'supplemental' to tier 1; and the third tier is 'intensive,' 'individualized,' and 'strategic.' Fourth, only if these multilayered attempts to modify the regular classroom pedagogical environment are unsuccessful is the prospect of an LD diagnosis considered. In summary, a child could be identified as having an LD if he or she consistently failed to perform at a level and progress at a rate comparable with the child's peers in general education after having participated in an evidence-based intervention.

Although there is considerable agreement in the field on the promise of RTI as a diagnostic paradigm, there are a variety of opinions regarding how, specifically, RTI should be quantified. Currently, the following paradigms are on trial: (1) Administer norm-referenced assessment batteries at the beginning and end of every school year to quantify the growth in response to intervention – students whose growth rate is below 'appropriate' should receive additional intervention, and (2) administer norm-referenced assessment batteries with a particular performance threshold (i.e., 25th percentile) – students whose performance is below this threshold should receive intensive interventions, and their performance should be monitored at least four times a year. There is also significant theoretical and experimental evidence suggesting the need for and importance of continuous progress monitoring with frequent (e.g., weekly) assessments of improvement. Currently, however, there are concerns about both approaches because of a lack of trained educational and practical professionals equipped to translate and implement research-based interventions into the everyday life of American schools. Since the 2004 reauthorization of IDEA, local education agencies have been in search of new robust solutions for identifying LDs that will meet the regulations of federal laws. RTI-based approaches to LD diagnosis present considerable challenges for all professionals involved in the realization of IDEA: general and special education teachers, diagnosticians (psychologists and psychiatrists), and school psychologists. The heart of this challenge is the lack of operationalization and practical guidelines that can be easily implemented at the 'frontiers' of diagnosing and treating children with LDs.

The majority of students with LDs are identified in middle and high school: Early years of schooling might simply be insufficient for exposing and making evident a deficit in a particular academic domain. As mentioned, the core conceptual piece of the LD definition is that the deficit could have not been predicted reliably prior to the child's school entry because a child with LDs demonstrates otherwise typical levels of cognitive functioning.

Previously when the discrepancy criteria were applied, the diagnosis of LD was different from other forms of learning difficulties because of its stress on the specificity of the deficit (i.e., a discrepancy was expected not in all academic domains, but in a specific academic domain). The introduction of RTI-based approaches to diagnosis makes the question of differential diagnosis somewhat difficult to address. In fact, students with mental retardation, emotional or behavior disorders, ADHD, and other childhood and adolescent disorders might also exhibit low responsiveness to intervention. Yet, their nonresponsiveness will occur for reasons very different from those of students with LDs. In other words, if RTI cannot differentiate LDs from other diagnoses where learning difficulties are present but nonspecific, can RTI even be considered as a classification/diagnostic instrument (Mastropieri and Scruggs, 2005)?

Although this question has been raised, it has not yet been answered. The pre-2004 conceptualization of LDs assumed that the texture of LDs was in deficient (or different, atypical) psychological processing of information. In other words, the field was driven by the assumption that LDs were likely to represent a dysfunction in one or more basic psychological processes (e.g., phonological processing, sustained attention, different types of memory, executive functioning). These deficient processes in turn can slow down or inhibit mastery of a particular academic domain (e.g., reading or mathematics). Under this assumption, intensive academic instruction could improve performance in specific academic domains but could not treat the disorder. Even if reading improves as a result of intervention, in this paradigm the disorder might remanifest as a deficiency in a bordering domain (e.g., writing). In other words, although reading skills might be enhanced, the deficient psychological skills might impede some other academic domain of functioning.

Throughout the existence of the category of specific LDs, there has been a consistent and strong drive from parents, researchers, and educators for differentiating these disorders from generic learning difficulties. In its current iteration, RTI does not differentiate nonspecific and specific learning difficulties, because nonresponsiveness to intervention can occur with a variety of developmental disorders. In sum, because IDEA preserved the category of SLDs, there is a new huge task to differentiate specific and nonspecific learning difficulties by means of RTI and possibly other methods in the field.

One of these 'other' methods has to do, of course, with psychological testing. Many researchers argue for the necessity of maintaining the role of psychoeducational and neuropsychological tests on a variety of indicators, including IQ, in establishing LD diagnosis (Mastropieri and Scruggs, 2005; Semrud-Clikeman, 2005).

## 2.38.7 Etiology

There is a consensus in the field that LDs arise from intrinsic factors and have neurobiological bases, specifically atypicalities of brain maturation and function. There is a substantial body of literature convincingly supporting this consensus and pointing to genetic factors as major etiological factors of LDs. The working assumption in the field is that these genetic factors affect the development, maturation, and functional structure of the brain and in turn influence cognitive processes associated with LDs. Yet the field is acutely aware that a number of external risk factors, such as poverty and lack of educational opportunities, affect patterns of brain development and function and, correspondingly, might worsen the prognosis for biological predisposition for LDs or act as a trigger in LD manifestation.

Although this model, in main strokes, appears to be relevant to all LDs, far more research on relevant genes and brain structure and function is available for children with SRD than for any other LD. Thus, illustrative findings are presented here from SRD (for a more comprehensive review, see Grigorenko, 2007).

Multiple methodological techniques, such as electroencephalograms, event-related potentials, functional resonance imaging, magnetoencephalography, positron emission tomography, and transcranial magnetic stimulation, have been used to elicit brain–reading relationships (for recent reviews, see Price and Mechelli, 2005; Shaywitz and Shaywitz, 2005; Simos et al., in press). When data from multiple sources are combined, it appears that a developed, automatized skill of reading engages a wide bilateral (but predominantly left-hemispheric) network of brain areas passing activation from occipitotemporal, through temporal (posterior), toward frontal (precentral and inferior frontal gyri) lobes. Clearly, the process of reading is multifaceted and involves evocation of orthographical, phonological, and semantic representations that in turn call for the activation of brain networks participating in visual, auditory, and conceptual processing. Correspondingly, it is expected that the areas of activation serve as anatomic substrates supporting all these types of representation and processing.

Somewhat surprisingly, per recent reviews, there appear to be only four areas of the brain of particular, specific interest with regard to reading. These areas are the fusiform gyrus (i.e., the occipitotemporal cortex in the ventral portion of Brodmann's area 37, BA 37), the posterior portion of the middle temporal gyrus (roughly BA 21, but possibly more specifically, the ventral border with BA 37 and the dorsal border of the superior temporal sulcus), the angular gyrus (BA 39), and the posterior portion of the superior temporal gyrus (BA 22).

It is also important to note the developmental changes in patterns of brain functioning that occur with increased mastery of reading skill: progressive, behaviorally modulated development of left-hemispheric 'versions' of these areas and progressive disengagement of right-hemispheric areas. In addition, there appears to be a shift of regional activation preferences. The frontal regions are used by fluent more than by beginning readers, and readers with difficulties activate the parietal and occipital regions more than the frontal regions.

In an attempt to understand the mechanism of the 'deficient' pattern of brain activation while engaged in reading, researchers are looking for genes that might be responsible, at least partially, for these observed differences in functional brain patterns. This search is supported by a set of convergent lines of evidence (for reviews, see Fisher and DeFries, 2002; Grigorenko, 2005; Barr and Couto, in press). First, SRD has been considered a familial disorder since the late nineteenth century. This consideration is grounded in years of research into the familiality of SRD (i.e., similarity on the skill of reading among relatives of different degree), characterized by studies that have engaged multiple genetic methodologies, specifically twin (Cardon et al., 1994, 1995; Byrne et al., 2005), family (Wolff and Melngailis, 1994; Grigorenko et al., 1997; Cope et al., 2005) and sib-pair designs (Francks et al., 2004; Ziegler et al., 2005). Although each of these methodologies has its own resolution power to explain similarities among relatives by referring to genes and environments as sources of these similarities and obtaining corresponding estimates of relative contributions of genes and environments, all methodologies have produced data that unanimously point to genetic similarities as the main source of familiality of SRD.

Today, it is assumed that multiple genes contribute to the biological risk factor that runs in families and forms the foundation for the development of SRD. Specifically, nine candidate regions of the human genome have been implicated (Grigorenko, 2005). These regions are recognized as SRD candidate regions; they are abbreviated as *DYX1–9*

(DYX for dyslexia, a term often used to refer to SRD) and refer to the regions on chromosomes 15q, 6p, 2p, 6q, 3cen, 18p, 11p, 1p, and Xq, respectively. Each of these regions harbors dozens of genes, so clearly, the field offers empirical validation that multiple genes contribute to the manifestation of SRD. A number of different research groups are actively at work on these genetic regions in an attempt to identify plausible candidate genes. Four successful attempts have been announced in the literature: one for the 15q region, the candidate gene known as *DYX1C1* (Taipale et al., 2003); two for the 6p region, the candidate gene known as *KIAA0319* (Francks et al., 2004; Cope et al., 2005) and the candidate gene knows as *DCDC2* (Meng et al., 2005; Schumacher et al., 2006); and one for the 3cen region, *ROBO1* (Hannula-Jouppi et al., 2005). Although the field has not yet converged on 'firm' candidates, it is remarkable and of great scientific interest that all four current candidate genes for SRD are involved with biological functions of neuronal migration and axonal crossing. Thus, all these genes are plausible candidates for understanding the pattern of brain functioning in SRD described earlier.

## 2.38.8 Relevant Theoretical Models and Considerations

As mentioned earlier, the literature on LDs is uneven, with the vast majority relating to SRD. Correspondingly, here I summarize the so-referred overarching model of LDs (Fletcher et al., 2007). Subsequently, I illustrate this model with detailed references to SRD. The overarching LD model delineates multiple levels of analyses and evidence.

According to this general model, LDs are anchored in a domain of particular academic difficulties (e.g., reading, spelling, computing, and writing). Correspondingly, the identification of an LD assumes that a diagnosis can be validly and reliably established on the basis of observed repeated patterns of weaknesses in a particular academic domain in the presence of strengths in all or some other academic domains. Thus, concerns, referrals, and diagnostic assessments are always centered on a particular academic domain that defines the content of LD. Correspondingly, the first step in LD identification is documenting the presence of a consistent failure or academic skill deficits, when compared with peer performance, on a set of specific tasks. Thus, behavioral presentation in a particular academic domain is the first level of analysis in the pyramid of LD diagnoses. However, the presence of an academic deficit is a necessary but insufficient condition for establishing an LD diagnosis.

The second level of analysis pertains to capturing individual characteristics of the child for whom an LD diagnosis is considered. Specifically, at this level, clusters of child characteristics are considered within the paradigm of inclusion and exclusion criteria of the LD category. Typically, at this level, the information is gathered in four directions: (1) pertaining to the academic domain of concern and cognitive processing known to be relevant to this particular domain, (2) pertaining to other academic domains in which the child demonstrates average or above-average levels of performance, (3) indicators of general cognitive functioning, and (4) other noncognitive and nonacademic domains of child's functioning (e.g., motivation, neurological and psychiatric indicators). Obviously, the information gathered at (1) is used within the context of inclusion and the information gathered in (2)–(4) within the context of exclusion criteria. It is critically important that there are well-developed psychological models available both for (1) and (2). For example, to identify LD in reading (SRD), it is important to know what cognitive processes constitute the texture of this academic skill. Similarly, since academic skills tend to correlate substantially in typically developing children, it is important to know what SRD and, for example, specific math disability (SMD) have in common and how they differ in terms of overlapping and specific psychological processes. To illustrate this level of analysis, I discuss modern psychological models of SRD below.

The third level of analysis involves both causal and associated etiological factors of LD. Specifically, a number of risk and protective factors rooted in the child's biology (e.g., gene and brain factors) and environment (e.g., school, neighborhood, and family environment factors) are considered at this level. The point here is to capitalize on the evidence in the field to differentiate LDs and underachievement, specific and nonspecific LDs, and specific LDs and comorbid conditions.

It is important to note that this model allows a diagnostician to move both up and down. The expectation is that the information converges across all three levels of analysis, and the diagnosis of LD is reliably established. However, it is possible, especially with young children, that the first 'level of entry' into the model is through cognitive processes that constitute the texture of the skill and thus emerge prior to the acquisition of the skill; for example, a child having difficulty mastering rhymes and letters might be identified as at risk for reading failure prior to entering formal reading instruction (Lonigan, 2003). Similarly, it is possible to enter the model through the level of biological risk factors; for example, given that SRD appears to be genetic, a child whose parents both have difficulty reading is at higher risk for SRD than is a child from a risk-free family (Gallagher et al., 2000; Lyytinen and Lyytinen, 2004). But, again, no matter what level of analysis this overarching model is entered through, it is very important that there are evidence-based models of acquisition of a particular skill (e.g., reading or mathematics) that is challenged in an LD.

Although psychological models of other LDs have been developed, here only those for SRD are exemplified for illustration purposes.

So far, there have been only generic references to the disruption of both the acquisition and mastery of reading skills that constitute the texture of SRD. When this generic reference is closely considered, another massive body of literature materializes: (1) cognitive psychology literature on types of representation of information involved in reading (i.e., reading involves the translation of meaningful symbolic visual codes (orthographical representation) into pronounceable and distinguishable sounds of language (phonological representation) so a meaning (semantic representation) arises) (Harm and Seidenberg, 2004); (2) developmental psychology literature on when these representations develop and what might cause the development of a dysfunctional representational system (Karmiloff-Smith, 1998); and (3) educational psychology literature on how the formation of functional representations can be aided or corrected when at risk for malfunction (Blachman et al., 2004).

Here only brief commentaries relevant to these literatures are offered. Today, given the predominance of the phonology-based connectionist account of SRD, behavioral manifestation of SRD is captured through a collection of highly correlated psychological traits. Although different researchers use different terms for specific traits, these can be loosely structured into groups aimed at capturing different types of information representation, for example: (1) performance on orthographic choice or homonym choice judgment tasks for quantifying parameters of orthographical representation; (2) phonemic awareness, phonological decoding, and phonological memory for quantifying phonological representation; and (3) vocabulary and indices of comprehension at different levels of linguistic processing for quantifying semantic representation. Correspondingly, in studies of the etiology, development, and educational malleability of SRD, the quantification of the disorder is carried out through these various traits (or components of SRD). Thus, many studies attempt to subdivide SRD into its components and explore their etiological bases, developmental trajectories, and susceptibility to pedagogical interventions separately as well as jointly.

Of note is that similar developments with regard to dissection of an academic skill and differentiation of componential psychological processes contributing to this skill have been taking place in the studies of acquisition of other academic skills, for example, mathematics (Butterworth, 2005; Geary, 2005; Fuchs et al., 2006; Fletcher et al., 2007).

## 2.38.9 Manifestation and Life Course

There is an accepted understanding in the field that LDs are typically lifelong disorders, although their manifestations might and often do vary depending on developmental stage and demands of the environment (e.g., school, work, retirement) imposed on an individual at a particular time. This understanding assumes that LDs do not manifest themselves exclusively in academic settings. In fact, although it might be successfully remediated during schooling, a particular LD might need further assistance and remediation in later years (e.g., as a part of the workforce). Although the literature on adults with LDs is still somewhat limited, there is an accumulation of evidence that LDs constitute a serious public health problem even after schooling. Such evidence is particularly rich in the field of studies of SRD.

LDs are comorbid with a number of other disorders typically diagnosed in childhood or adolescence, especially attention deficit (Semrud-Clikeman et al., 1992) and disruptive behavior disorders (Grigorenko, 2006). LDs also often co-occur with anxiety and depression (Martinez and Semrud-Clikeman, 2004). Correspondingly, individuals with LDs are at higher risk for developing other mental health problems.

Yet, the main drawback for individuals with specific LDs has to do with their educational achievement. On average, only ~50% of students aged 14 and older diagnosed with LDs graduate with regular high school diplomas. The dropout rate among these students is very high (~45%), and it is even higher for underrepresented minority students. The employment prospects of these students are also troublesome – only about 60% of student ages 14 and older diagnosed with LDs have paid jobs outside the home.

Thus, it is important to realize that the impact of LDs is not limited to any one academic domain (e.g., reading or mathematics); these are lifetime disorders with wide-ranging consequences.

## 2.38.10 Treatment, Remediation, Intervention, and Prevention

Currently, there are no approved medical treatments for children with LDs. There is a consensus in the field that children with LDs should be provided special education and related services upon establishment of their eligibility and determination of the necessity, content, duration, and desired outcomes of such education and services.

Yet, in much of the literature, many educators have expressed concern with the possible presence of faulty identification procedures in states and districts across the country, which has resulted in the possible abuse of the classification and service systems. The ever-growing number of children identified with LDs might indicate that this category has become a 'trap' for lower-performing students, irrespective of an LD diagnosis.

In response to this concern, the 2004 reauthorization of IDEA makes reference to a set of prevention mechanisms intended to establish a better classification strategy for identifying children with LDs. By law, schools need to implement systemic models of prevention that address (1) primary prevention: the provision of high-quality education for all children; (2) secondary prevention: targeted, scientifically based interventions for children who do not respond to primary prevention; and (3) tertiary prevention: the provision of intensive individualized services and interventions for those children who have not responded to high-quality instruction or subsequent intervention efforts. As per new regulations, it is assumed that this third group of children, namely those children who have failed to respond to age-, language-, and culture-appropriate, evidence-based, domain-specific instruction (e.g., in reading or mathematical cognition), can be identified as eligible for special education services. These prevention mechanisms are also assumed to be used as diagnostic mechanisms (see earlier discussion of RTI). This circular system of an outcome of intervention being also an entry point to diagnosis is currently creating significant turmoil in the literature and in practice.

In general, RTI approaches are conceived as a twofold simultaneous realization of high-quality, domain-specific instruction and continuous formative evaluation of students' performance and learning (Mellard et al., 2004a,b). In other words, RTI refers to ongoing assessment of students' response to evidence-based pedagogical interventions in particular academic domains. Thus, it is assumed that LDs can be identified only when underachievement related to poor instruction is ruled out. (It is also important to note that the primary diagnosis of LD is established only in the absence of other neuropsychaitric conditions.) Although it exists in a number of alternative forms, RTI includes eight central features and six common attributes. Among the central features linking all forms of RTI are: (1) high-quality classroom instruction, (2) research-based instruction, (3) classroom performance measures, (4) universal screening, (5) continuous progress monitoring, (6) research-based intervention, (7) progress monitoring during intervention, and (8) fidelity measures. Among common attributes of different RTI models, there are concepts of (1) multiple tiers; (2) transition from instruction for all to increasingly intense interventions; (3) implementation of differentiated curricula; (4) instruction delivered by staff other than the classroom teacher; (5) varied duration, time, and frequency of intervention; and (6) categorical or noncategorical placement decisions (Graner et al., 2005). Clearly, the concept of RTI is centered on the field's definition of high-quality research-validated instruction. It is important to note that, although there is growing consensus on the critical elements for effective reading instruction (e.g., Foorman et al., 2003), other domains of teaching for academic competencies are far from consensus-driven (*See* Chapters 2.37, 2.43).

There are numerous examples of RTI-based treatment of LDs; two often-cited ones are the Minneapolis Public School's Problem Solving Model, in action since 1994 (Marston et al., 2003), and the Heartland (Iowa) Area Education Association's Model, implemented in 1986 (Ikeda and Gustafson, 2002). The Minneapolis model is a three-tier intervention model where the referral to special education is made only after consecutive failures to benefit from instruction throughout all three tiers of pedagogical efforts. The Iowa model originally included four tiers, where the third tier was subdivided into two related steps, but it was then collapsed into one tier, similar to the

Minneapolis model. Unfortunately, neither model has published empirical data on its effectiveness. Yet, years of implementation have resulted in appreciation from the communities they serve and in a stable, relatively small special education population.

Currently, the concept of RTI is under careful examination by researchers supported by both the U.S. Department of Education and the National Institute of Child Health and Development. The future of RTI and its role in diagnosing and treating specific LDs is dependent on answers to critical questions: (1) whether an RTI model can be implemented on a large scale; (2) how an RTI model can be used for LD eligibility determination; (3) whether an RTI is an effective prevention system; and (4) whether RTI enhances LD determination and minimizes the number of false positives.

## 2.38.11 Conclusion

I began this chapter with a brief discussion of the concept of developmental disorders of learning and with the concern that there is no single definition of this concept. In fact, the discussion of the 'multi-representativeness' of this concept in the two main diagnostic schemes (DSM-IV and ICD-10) led me to substitute it with the concept of LD. The discussion of the category of LD in this chapter hopefully stresses the importance of this concept and, indirectly, the concept of developmental disorders of learning. The LD concept is important because of its (1) prevalence, (2) implications for countless school-age students and adults, and (3) importance for the development of fundamental models of acquisition of cognitive skills and strategies of prevention and remediation of failure of acquisition.

Currently, students with specific LDs constitute about half of all students served under IDEA. Effective identification of such students and their efficacious and efficient remediation are crucial steps to address their individual educational needs and to provide them with adequate and equal life opportunities.

Given changes in IDEA 2004, it is no surprise that RTI is been central to current discourse on specific LDs. RTI is essential to the professional discussions of educators, diagnosticians, and policy makers because of its promise to alleviate many long-standing concerns with the IQ/aptitude–achievement discrepancy model predominant in the field of LDs for the last 30 years. At this point, however, RTI has yet to deliver on its promise. If RTI succeeds, numerous benefits to educational systems and individuals might be realized (Graner et al., 2005). Specifically, as for the system, many inappropriate referrals might be eliminated to increase the legitimacy and fair nature of 'true' referrals; the costs of special education services might be reduced; various gender and ethnicity biases might be minimized; and accountability for student learning might increase. As for individuals, because the 'labeling' criteria will change, there will be less time for a student to demonstrate a 'true' failure in achieving the stipulated discrepancy value – prevention and remediation efforts are expected to start as early as possible; instruction will be individualized; identification will be focused on achievement rather than on aptitude–achievement discrepancy; and minimized labeling should result in less social stigma.

Yet, these are only expectations for now, and the immediate future will show whether RTI is a viable replacement to the discrepancy criteria.

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## References

Aaron PG (1997) The impending demise of the discrepancy formula. *Rev. Educ. Res.* 67: 461–502.

American Psychiatric Association (1994) *Diagnostic and Statistical Manual of Mental Disorders,* 4th edn. Washington, DC: American Psychiatric Association.

Barr CL and Couto JM (in press) Molecular genetics of reading. In: Grigorenko EL and Naples A (eds.) *Single-Word Reading: Cognitive, Behavioral and Biological Perspectives.* Mahwah, NJ: Lawrence Erlbaum.

Blachman BA, Schatschneider C, Fletcher JM, et al. (2004) Effects of intensive reading remediation for second and third graders and a 1-year follow-up. *J. Educ. Psychol.* 96: 444–461.

Butterworth B (2005) Developmental dyscalculia. In: Campbell JID (ed.) *Handbook of Mathematical Cognition*, pp. 455–467. New York: Psychology Press.

Byrne B, Wadsworth S, Corley R, et al. (2005) Longitudinal twin study of early literacy development: Preschool and kindergarten phases. *Sci. Stud. Reading* 9: 219–235.
Cardon LR, Smith SD, Fulker DW, Kimberling WJ, Pennington BF, and DeFries JC (1994) Quantitative trait locus for reading disability on chromosome 6. *Science* 226: 276–279.
Cardon LR, Smith SD, Fulker DW, Kimberling WJ, Pennington BF, and DeFries JC (1995) Quantitative trait locus for reading disability: Correction. *Science* 268: 1553.
Cope N, Harold D, Hill G, et al. (2005) Strong evidence that KIAA0319 on chromosome 6p is a susceptibility gene for developmental dyslexia. *Am. J. Hum. Genet.* 76: 581–591.
Council of Parent Attorneys and Advocates (2004) *H. R. 1350 Individuals with Disabilities Education Improvement Act of 2004 Compared to IDEA 97*. Warrenton, VA: Council of Parent Attorneys and Advocates, Inc.
Deshler DD, Mellard DF, Tollefson JM, and Byrd SE (2005) Research topics in responsiveness to intervention: Introduction to the special series. *J. Learn. Disabil.* 38: 483–484.
Donovan MS and Cross CT (2002) *Minority Students in Special and Gifted Education*. Washington, DC: National Academy Press.
Fisher SE and DeFries JC (2002) Developmental dyslexia: Genetic dissection of a complex cognitive trait. *Nat. Rev. Neurosci.* 3: 767–780.
Fletcher JM, Lyon GR, Barnes M, et al. (2002) Classification of learning disabilities: An evidence-based evaluation. In: Bradley R, Danielson L, and Hallahan DP (eds.) *Identification of Learning Disabilities: Research to Practice*, pp. 185–250. Mahwah, NJ: Lawrence Erlbaum.
Fletcher JM, Lyon GR, Fuchs LS, and Barnes MA (2007) *Learning Disabilities*. New York: Guilford.
Foorman BR, Breier JI, and Fletcher JM (2003) Interventions aimed at improving reading success: An evidence-based approach. *Dev. Neuropsychol.* 24: 613–639.
Francis DJ, Fletcher JM, Stuebing KK, Lyon GR, Shaywitz BA, and Shaywitz SE (2005) Psychometric approaches to the identification of LD: IQ and achievement scores are not sufficient. *J. Learn. Disabil.* 38: 98–108.
Francks C, Paracchini S, Smith SD, et al. (2004) A 77-kilobase region on chromosome 6p22.2 is associated with dyslexia in families from the United Kingdom and from the United States. *Am. J. Hum. Genet.* 75: (1046–1058).
Franklin BM (1987) The first crusade for learning disabilities: The movement for the education of backward children. In: Popkewitz T (ed.) *The Foundation of the School Subjects*, pp. 190–209. London: Falmer.
Fuchs LS, Fuchs D, Compton DL, et al. (2006) The cognitive correlates of third-grade skill in arithmetic, algorithmic computation, and arithmetic word problems. *J. Educ. Psychol.* 98: 29–43.
Gallagher AM, Frith U, and Snowling MJ (2000) Precursors of literacy delay among children at genetic risk of dyslexia. *J. Child Psychol. Psychiatry* 4: 202–213.
Geary DC (2005) Role of cognitive theory in the study of learning disability in mathematics. *J. Learn. Disabil.* 38: 305–307.
Graner PS, Faggetta-Luby MN, and Fritschmann NS (2005) An overview of responsiveness to intervention: What practitioners ought to know. *Top. Lang. Disord.* 25: 93–105.
Gresham FM, Reschly DJ, Tilly WD, et al. (2004) Comprehensive evaluation of learning disabilities: A response to intervention perspective. *Sch. Psychol.* 59: 26–29.
Grigorenko EL (2005) A conservative meta-analysis of linkage and linkage-association studies of developmental dyslexia. *Sci. Stud. Reading* 9: 285–316.
Grigorenko EL (2006) Learning disabilities in juvenile offenders. *Child Adolesc. Psychiatr. Clin. N. Am.* 15: 353–371.
Grigorenko EL (2007) Triangulating developmental dyslexia: Behavior, brain, and genes. In: Coch D, Dawson G, and Fischer K (eds.) *Human Behavior and the Developing Brain*, pp. 117–144. New York, NY: Guilford Press.
Grigorenko EL, Wood FB, Meyer MS, et al. (1997) Susceptibility loci for distinct components of developmental dyslexia on chromosomes 6 and 15. *Am. J. Hum. Genet.* 60: 27–39.
Haight SL, Patriarca LA, and Burns MK (2002) A statewide analysis of eligibility criteria and procedures for determining learning disabilities. *Learn. Disabil. Multidisciplinary J.* 11: 39–46.
Hallahan DP and Mercer CR (2002) Learning disabilities: Historical perspectives. In: Bradley R, Danielson L, and Hallahan DP (eds.) *Identification of Learning Disabilities: Research to Practice*, pp. 1–67. Mahwah, NJ: Lawrence Erlbaum.
Hannula-Jouppi K, Kaminen-Ahola N, Taipale M, et al. (2005) The axon guidance receptor gene *ROBO1* is a candidate dene for developmental dyslexia. *PLoS Genet.* 1: e50.
Harm MW and Seidenberg MS (2004) Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychol. Rev.* 111: 662–720.
House AE (2002) *DSM-IV Diagnosis in the Schools*. New York: Guilford Press.
IDEA Data (2006) Part B Annual Report Tables. IDEA Data Website. https://www.ideadata.org/PartBReport.asp (accessed May 2007)
Ikeda MJ and Gustafson JK (2002) *Heartland AEA 11's Problem Solving Process: Impact on Issues Related to Special Education* (No. 2002–01). Johnston, IA: Heartland Area Educational Agency 11.
Karmiloff-Smith A (1998) Development itself is the key to understanding developmental disorders. *Trends Cogn. Sci.* 2: 389–398.
Kavale KA and Reese JH (1992) The character of learning disabilities: An Iowa profile. *Learn. Disabil. Q.* 15: 74–94.
Lonigan CJ (2003) Development and promotion of emergent literacy skills in children at-risk of reading difficulties. In: Foorman BR (ed.) *Preventing and Remediating Reading Difficulties*, pp. 23–50. Baltimore, MD: York Press.
Lyytinen P and Lyytinen H (2004) Growth and predictive relations of vocabulary and inflectional morphology in children with and without familial risk for dyslexia. *Appl. Psycholinguist.* 25: 397–411.
Mandlawitz M (2006) *What Every Teacher Should Know about IDEA 2004*. Boston: Allyn and Bacon.
Marston D, Muyskens P, Lau MY-Y, and Canter A (2003) Problem-solving model for decision making with high-incidence disabilities: The Minneapolis experience. *Learn. Disabil. Res. Pract.* 18: 187–200.
Martinez RS and Semrud-Clikeman M (2004) Emotional adjustment and school functioning of young adolescents with multiple versus single learning disabilities. *J. Learn. Disabil.* 37: 411–420.
Mastropieri MA and Scruggs TE (2005) Feasibility and consequences of response to intervention: Examination of the issues and scientific evidence as a model for the identification of individuals with learning disabilities. *J. Learn. Disabil.* 38: 525–531.
Mellard DF, Byrd SE, Johnson E, Tollefson JM, and Boesche L (2004a) Foundations and research on identifying model Responsiveness-to-Intervention sites. *Learn. Disabil. Q.* 27: 243–256.
Mellard DF, Deshler DD, and Barth A (2004b) LD identification: It's not simply a matter of building a better mousetrap. *Learn. Disabil. Q.* 274: 229–242.
Meng H, Smith SD, Hager K, et al. (2005) DCDC2 is associated with reading disability and modulates neuronal development in the brain. *Proc. Natl. Acad. Sci. USA* 102: 17053–17058.

Mercer CD, Jordan L, Allsopp DH, and Mercer AR (1996) Learning disabilities definitions and criteria used by state education departments. *Learn. Disabil. Q.* 19: 217–232.
National Center for Education Statistics (2005a) *National Assessment of Educational Progress: The Nation's Report Card: Reading (2005).* National Center for Education Statistics, U.S. Department of Education, Institute of Education Sciences. http://nces.ed.gov/nationsreportcard/pdf/main2005/2006451.pdf (accessed May 2007)
National Center for Education Statistics (2005b) Number and percent of children served under Individuals with Disabilities Education Act, Part B, by age group and state or jurisdiction: Selected years, 1990–91 to 2003–04. National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education. http://nces.ed.gov/programs/digest/d04/tables/dt04_054.asp (accessed May 2007)
President's Commission on Excellence in Special Education (2002) *A New Era: Revitalizing Special Education for Children and Their Families.* Washington, DC: U.S. Department of Education.
Price CJ and Mechelli A (2005) Reading and reading disturbance. *Curr. Opin. Neurobiol.* 15: 231–238.
Reid DK and Valle JW (2004) The discursive practice of learning disability. *J. Learn. Disabil.* 37: 466–481.
Reschly DJ (1996) Functional assessment and special education eligibility. In: Stainback W and Stainback S (eds.) *Controversial Issues Confronting Special Education: Divergent Perspective,* 2nd edn., pp. 115–128. Boston: Allyn and Bacon.
Reschly DJ and Ysseldyke JE (2002) Paradigm shift: The past is not the future. In: Thomas A and Grimes J (eds.) *Best Practices in School Psychology,* 4th edn., pp. 3–20. Bethesda, MD: National Association of School Psychologists.
Schumacher J, Anthoni H, Dahdouh F, et al. (2006) Strong genetic evidence of *DCDC2* as a susceptibility gene for dyslexia. *Am. J. Hum. Genet.* 78: 52–62.
Semrud-Clikeman M (2005) Neuropsychological aspects for evaluating learning disabilities. *J. Learn. Disabil.* 38: 563–568.
Semrud-Clikeman M, Biederman J, Sprich-Buckminster S, Lehman BK, Faraone SV, and Norman D (1992) Comorbidity between ADDH and learning disability: A review and report in a clinically referred sample. *J. Am. Acad. Child Adolesc. Psychiatry* 31: 439–448.
Shaywitz SE and Shaywitz BA (2005) Dyslexia (specific reading disability). *Biol. Psychiatry* 57: 1301–1309.
Simos PG, Billingsley-Marshall B, Sarkari S, and Papanicolaou AC (in press). Single-word reading: Perspectives from magnetic source imaging. In: Grigorenko EL and Naples A (eds.) *Single-Word Reading: Cognitive, Behavioral and Biological Perspectives.* Mahwah, NJ: Lawrence Erlbaum.
Sternberg RJ and Grigorenko EL (2002) Difference scores in the identification of children with learning disabilities: It's time to use a different method. *J. Sch.Psychol.* 40: 65–83.
Strydom J and du Plessis S (2000) Birth of a syndrome. In: *The Right to Read: Beating Dyslexia and Other Learning Disabilities.* Audiblox. http://www.audiblox2000.com/book2.htm (accessed May 2007)
Taipale M, Kaminen N, Nopola-Hemmi J, et al. (2003) A candidate gene for developmental dyslexia encodes a nuclear tetratricopeptide repeat domain protein dynamically regulated in brain. *Proc. Natl. Acad. Sci. USA* 100: 11553–11558.
U.S. Office of Education (1977) Assistance to states for education for handicapped children: Procedures for evaluating specific learning disabilities. *Fed. Regist.* 42: 65082–65085.
U.S. Office of Special Education Programs (2000) *History: Twenty-Five Years of Progress in Educating Children with Disabilities through IDEA*. Washington, DC: U.S. Department of Education.
Vaughn S and Fuchs LS (2003) Redefining learning disabilities as inadequate response to instruction: The promise and potential problems. *Learn. Disabil. Res. Pract.* 18: 137–146.
Wolff PH and Melngailis I (1994) Family patterns of developmental dyslexia. *Am. J. Med. Genet. B Neuropsychiatr. Genet.* 54: 122–131.
World Health Organization (2005) *International Statistical Classification of Diseases and Related Health Problems (The) ICD-10*, 2nd edn. Geneva: World Health Organization.
Ziegler A, Konig IR, Deimel W, et al. (2005) Developmental dyslexia – recurrence risk estimates from a German bi-center study using the single proband sib pair design. *Hum. Hered.* 59: 136–143.
Zigmond N (1993) Learning disabilities from an educational perspective. In: Lyon GR, Gray DB, Kavanagh JF, and Krasnegor NA (eds.) *Better Understanding Learning Disabilities: New Views from Research and Their Implications for Education and Public Policies*, pp. 251–272. Baltimore, MD: Paul H. Brookes Publishing.

# 2.39 Learning in Autism

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## 2.39.1 Introduction

Learning in autism is not a topic characterized by consensus. For example, the ability of autistics (see Sinclair, 1999, to appreciate our respectful use of the term 'autistic' rather than 'person with autism') to learn is considered nonexistent in the typical everyday environment (Lovaas and Smith, 2003) and fundamentally impaired (Klinger et al., 2006), but so astounding that the cognitive literature as a whole is insufficient to explain it (Atkin and Lorch, 2006). Autistic learning is recognized as distinctive (Volkmar et al., 2004) and singled out as subhuman (Tomasello et al., 2005), but is also considered unremarkable compared to nonautistic learning (Thioux et al., 2006). These apparently disparate accounts may be the result of autistic learning, in contrast to autistic perception, attention, and memory, being investigated in a piecemeal, *ad hoc* manner. This chapter will summarize a range of current and emerging proposals about autistic learning, examining each proposal's empirical basis and adding historical and thematic perspectives.

## 2.39.2 Autism: Classification and Description

Autism is a neurodevelopmental difference, classified as a pervasive developmental disorder in the DSM-IV (American Psychiatric Association, 1994) and diagnosed by atypical social interaction (e.g., "a lack of spontaneous seeking to share ... achievements with other people," American Psychiatric Association, 1994: 70), atypical communication (e.g., difficulty "sustain[ing] a conversation," American Psychiatric Association, 1994: 70), focused interests (e.g., "persistent preoccupation with parts of objects", American Psychiatric Association, 1994: 70), and atypical body mannerisms (e.g., "hand or finger flapping", American Psychiatric Association, 1994: 70). While autism is innate, the overt behaviors used to diagnose autism may not appear until the second year of life, but always appear before age 3. Autism is polygenic (with as yet no agreed-upon loci) and highly heritable, with a male:female ratio of approximately 4:1 and a prevalence of approximately 20/10 000. Two less well-defined pervasive developmental disorders are considered, with autism, to form the autistic spectrum. The first is Asperger syndrome, which shares the behavioral characteristics of autism but presents with a different developmental trajectory, featuring no delay in the onset of speech and measured intelligence in the normal range (Szatmari et al., 2000). The second is Pervasive Developmental Disorder, Not Otherwise Specified (PDD-NOS), defined as a subthreshold presentation of the behaviors used to diagnose autism. Prevalence across the autistic spectrum is roughly 60/10 000, and has been shown to be stable over time, as has autism prevalence (Chakrabarti and Fombonne, 2001, 2005). This review will concentrate on autism itself, as the bulk of the relevant research concerns this specific diagnosis.

In research, autistics are often divided into high- and low-functioning subgroups, based on a snapshot measurement of intelligence or developmental level. While this division is an efficient shorthand to denote whether participants fall into the range of diagnosable mental retardation, instruments normed for the nonautistic population are potentially misleading when applied to autistics (e.g., Mottron, 2004), and individuals' measured IQs may change dramatically over time, particularly before age 6 (e.g., Eaves and Ho, 2004; Gernsbacher, 2004). Autistics' average scores on intelligence test batteries (e.g., Wechsler scales) mask widely scattered subtest scores, raising the question of whether level of functioning can definitively be assigned even at any single point in time. The difficulty of assessing autistic intelligence is illustrated by recent epidemiology: The percentage of autistics who also meet current day criteria for mental retardation is reported as anywhere from 25–70% (Honda et al., 1996; Baird et al., 2000; Kielinen et al., 2000; Chakrabarti and Fombonne, 2001). The difficulty of assessing autistic intelligence is also illustrated via a speed-of-processing task known to be correlated with intelligence: Autistics assumed to be high- or low-functioning perform equally well, and as well as, nonautistics with Weschler IQs more than 2 or 3 standard deviations higher, respectively (Scheuffgen et al., 2000). Similarly, autistics' performance on Raven's Progressive Matrices, the preeminent measure of fluid intelligence, may significantly exceed their performance on Wechsler scales, suggesting that the high- versus low-functioning division is of questionable validity (Dawson et al., 2007).

Autism has no known etiology in the majority of cases, but in a minority of cases, an associated syndrome can be identified (e.g., tuberous sclerosis, West syndrome). In research, such syndromes are frequently cited as exclusion criteria or possible confounds, and the distinction between etiological autism (associated with such syndromes) and idiopathic autism (not associated with such syndromes) has been important in ascertaining whether epilepsy is associated with autism or with other conditions associated with autism. Indeed, evidence points to epilepsy not being associated with idiopathic autism (Pavone et al., 2004; Battaglia and Carey, 2006).

Another division is often drawn between savant autistics, whose uneven profile of abilities encompasses exceptional expertise in one or more characteristic areas (e.g., calendar calculation, drawing in perspective), and nonsavant autistics, whose uneven profile of abilities has not progressed to that level of atypical expertise. Savant abilities are far more prevalent in the autistic than in the nonautistic population (1 in 10 versus 1 in 2000; Hill, 1977; Rimland, 1978), and are consistently linked with autistic traits (Heaton and Wallace, 2004). Savant abilities and their significance for the study of autistic learning will be explored in later sections.

Few aspects of neurology have not been proposed as being atypical in autism. For example, regions of reported neurofunctional atypicalities range from the brainstem to the inferior frontal gyrus, while reported neuroanatomical atypicalities range from increased white and gray matter volume (e.g., Hazlett et al., 2005) to more densely packed cells and increased numbers of cortical minicolumns (Casanova et al., 2002). Neurofunctional connectivity has been suggested to be atypical (e.g., Just et al., 2004), and neural resources may be atypically allocated or rededicated (e.g., Turkeltaub et al., 2004; Koshino et al., 2005). Virtually every fundamental human cognitive and affective process, singly or as part of an overarching model, has been proposed to be dysfunctional or absent in autism, while persistent findings of superior performances by autistics are often interpreted as evidence of neurological and cognitive pathology (e.g., Langdell, 1978; Shah and Frith, 1983, 1993; Heaton et al., 1998; Beversdorf et al., 2000; Ropar and Mitchell, 2002; Toichi et al., 2002; Chawarska et al., 2003; Just et al., 2004; for analysis and perspective, see Baron-Cohen, 2005; Gernsbacher et al., 2006; Mottron et al., 2006). Thus, autism has been prolifically studied but remains poorly understood.

## 2.39.3 History and Background: Accounts of Autistic Learning

Accounts of recognizably autistic learning date back more than a century and precede the establishment of autism as a diagnosis. There are reports of individuals with an incongruous repertoire of abilities: Apparently general cognitive impairment coupled with outstanding performance in specific areas, such as music, drawing, calculation, and memory (see Treffert, 1988, for a review). The branding of these individuals as 'idiot savants,' a practice that endured until recently, is evidence of how autistic learning has been and may still be conceptualized.

Kanner (1943) first proposed autism as a distinct condition. His landmark description of 11 autistic children included observations about their unusual pattern of learning, evident from early development. The children precociously acquired quantities of specific information, from the names of objects, people, and presidents; to numbers and the alphabet; to fine discriminations between musical compositions; to the texts of psalms, poems, and nursery rhymes (sometimes in several languages); to lists of plants and animals as well as "long and unusual words" (p. 243); to the contents of encyclopedias. Kanner characterized much of this learning, particularly in 2- and 3-year old children, as a "valueless" (p. 243) obstacle to genuine communication, but also reported excellent abilities in reading, spelling, and vocabulary. There were no difficulties with plurals, tenses, and grammar; an early reversal of pronouns (e.g., using 'you' for 'I') became less evident over time. The children were characterized as having strong and independent interests; one child "displayed astounding purposefulness in the pursuit of self-selected goals" (Kanner, 1943: 232).

Kanner observed that mute autistic children, a minority in his original sample, had "astounded their parents by uttering well-formed sentences in emergency situations"; he concluded that mute autistic children may demonstrate that they have, while apparently silent, accumulated a "considerable store" of information about language (Kanner, 1949: 417–418). In a later paper, Kanner observed that autistic children were extremely difficult to teach in conventional ways: They "learn while they resist being taught." For example, they remained unimpressed with persistent attempts to prompt them to walk, then spontaneously walked when this was "least expected." One autistic boy's parents undertook strenuous efforts, involving many hours per day, to teach and exhort him to speak. These efforts failed, but "at about $2\frac{1}{2}$ years of age, he spoke up and said 'Overalls,' a word which was decidedly not part of the teaching repertoire." (Kanner, 1951: 23–24).

Independently of Kanner, Asperger (1944/1991) also proposed autism as a distinct condition. In his seminal paper, Asperger recorded observations about autistic learning that were strikingly similar to Kanner's. Autistic children, some of whom were described as learning to read "particularly easily" (p. 75), were "almost impossible to teach" (p. 49) and could not "learn from adults in conventional ways" (p. 56) or "assimilate the ready-made knowledge and skill that others present" (p. 63). These children were poor in what Asperger called mechanical learning, or learning to do as others do automatically. However, they excelled in a kind of original thinking that Asperger called autistic intelligence. Asperger described an autistic child who spontaneously learned basic principles of geometry by age 3, and cubic roots shortly thereafter, but "learnt or did not learn as the whim took him" (p. 88), with unfortunate results in school.

Both Kanner's and Asperger's accounts resonate with earlier reports of 'idiot savants.' In 1945, Scheerer and colleagues discussed Kanner's observations (1943) within an extensive descriptive and empirical account of a child, L., who today would be considered an autistic savant. Alongside apparently comprehensive limitations in behavior and intelligence, L. had excellent abilities in calendar calculation and music, as well as in learning and recall of words, events, facts, and numbers. Interest in these areas first appeared when L. was 3. L. was reported to be incapable of learning by instruction; he had "an inherent difficulty in learning by following instructions and explanations in a systematic way" (p. 2) and "never absorbed or learned in a normal fashion" (p. 59). He had absolute pitch and enjoyed playing the piano "for hours without being taught" (p. 2). His unusual range of abilities was hypothesized to arise from impaired abstraction, which resulted in "abnormal concreteness" (p. 61) and a facility in acquiring and manipulating information that typical individuals would judge as "senseless or peripheral or irrelevant" (Scheerer et al., 1945: 61).

Kanner considered that the atypical strengths and not the obvious difficulties of autistic children reflected their true potential, but Kanner provided limited empirical evidence to support his position, which has accumulated opposition over the years. For example, Klin et al. (1997) contended that autistics' 'splinter skills' overestimated their true abilities, had little relevance to real life, and existed against a context of pervasive deficiency (see also DeMyer et al., 1974; Prior, 1979; Volkmar and Klin, 2005). Similarly, focused abilities and interests have been characterized primarily as interfering with learning in autism and Asperger syndrome, rather than representing it (Volkmar and Klin, 2000; Klin et al., 2005). Distinctly autistic learning and intelligence have thus been considered pathological, misleading, and uninformative, if not mythical (e.g., Epstein et al., 1985; Shah and Frith, 1993; Green, 1999). This judgment leaves no plausible explanation for the conspicuous success of some autistics (e.g., a child who "did phenomenally well in mathematics, was sent to an accelerated school, and is now finishing the eleventh grade with top marks"; Kanner and Eisenberg, 1956: 86).

Specific traits investigated in follow-up studies (e.g., speech fluency or measured intelligence) have not been consistently predictive of outcomes (Howlin, 2005) or explanatory of why some autistics have done notably well (Asperger, 1944; Kanner, 1973; Szatmari et al., 1989). Indeed, both Kanner (1973) and Szatmari et al. (1989) reported that fortunate outcomes were unexpected; they could not have been predicted from early presentation or development. The success in university, including one MBA, of half of Szatmari et al.'s sample (less than 70% of whom had useful speech before age 5) was achieved by individuals who, like the successful autistics reported by Kanner, grew up before the era of early intervention programs. Similarly, an individual who Asperger (1944) followed for 30 years was "grossly autistic" (p. 88) throughout his life, with "impossible behavior" (p. 89), failure, and ineptness in multiple areas (language, daily life, social behavior). This individual pursued his early interest in mathematics and rapidly became a successful, if unusual, academic. Like Asperger, Kanner (1973) underlined the importance of focused interests and abilities through development as the means by which autistics could participate in and contribute to society.

Less fortunate autistics were placed in institutions, denied education, subject to useless and harmful treatments (e.g., "tranquilizers . . . pushed to the point of toxicity"; Kanner, 1971: 125), and were found to have poor outcomes (Rutter et al., 1967; Lockyer and Rutter, 1969; Kanner, 1971, 1973). In Rutter's (1966, 1970) sample, 56% of the 63 children had fewer than 2 years of school, and many had none at all, regardless of their measured abilities. More than half were institutionalized, and many endured deleterious or spurious treatments (e.g., electroconvulsive therapy, insulin coma, prefrontal lobotomy, prolonged psychoanalysis; from Rutter et al., 1967). Against this hazardous backdrop, many in Rutter's sample acquired reading abilities, several were employed, and some had academic achievements (e.g., in the areas of music and computer science). DeMyer et al. (1973) observed in their sample, 44% of whom were institutionalized, that a decrease over time in the performance IQs of poor-outcome autistics was related to an observed loss of their 'splinter skills.'

Descriptive and empirical accounts of autistics learning in unusual and successful ways have sporadically appeared and remained unexplained throughout the history of autism research. Autistics are no longer routinely institutionalized and are entitled to public education, but there continues to be a dearth of data linking early autism interventions to adult outcomes. Instead, there are data indicating that currently popular interventions may be unrelated to child outcomes (Gernsbacher, 2003; Eaves and Ho, 2004; Lord et al., 2006; Magiati et al., 2007). The educational and psychosocial intervention literature in autism, despite undeniable quantity and prominence, has failed to produce "a clear direct relationship between any particular intervention and children's progress" (National Research Council, 2001: 5).

## 2.39.4 Learning in the Autism Intervention Research

Comprehensive early intervention programs in autism have borrowed extensively from each other and have become progressively more similar (Dawson and Osterling, 1997; National Research Council, 2001; Kasari, 2006). A typical curriculum may, at the outset, involve series of trials for training eye contact ('look at me'), commands ('sit down,' 'stand up,' 'come here,' 'turn around'), motor imitation ('do this . . .'), followed by commands to point ('point to the . . .'), match, verbally imitate, and verbally label (see, e.g., Maurice et al., 1996). Comprehensive programs vary in their use of settings and structure (e.g., highly structured trials vs. more naturalistic approaches), in their use of procedures and techniques (e.g., prompting, reinforcement), in their incorporation of developmental and other theoretical considerations, etc. (Rogers and Ozonoff, 2006). Apart from their intensity (usually, more than 20 h per week) and their ideal of intervening as early as possible, they share the premise that autism represents a harmful deviation from (or multiple deviations from) typical development. They also share the goal of achieving, to the greatest extent possible, a typical developmental trajectory encompassing typical social, communicative, and adaptive behaviors. Failing to address presumed deviations or delays in early development is believed to result in autistics falling further and further behind, as autistic traits and abilities, which are seen as inadequate, inappropriate, or maladaptive, become entrenched obstacles to achieving the ideal typical trajectory. The promise that very early intervention will interrupt, reverse, prevent, and stop autism 'in its tracks' is avidly pursued (Cecil, 2004: 2).

The effectiveness of comprehensive early intervention programs is judged against autism's presumed poor prognosis, and according to the extent to which typical skills have successfully been acquired and atypical autistic behaviors have successfully been extinguished (Smith, 1999; Handleman and Harris, 2001). The possibility that a typical developmental trajectory and repertoire of behaviors may not be adaptive for autistics or beneficial for autistic learning has not yet been considered. Researchers have "studied the effectiveness of programs, not the appropriateness of various goals" (National Research Council, 2001: 41), while as yet providing no empirical foundation for the popular contention that intensive early interventions result in successful, independent typical adults. The best adult outcomes in the peer-reviewed literature belong to autistics whose early development predates the availability of these interventions and was in no way typical (e.g., Kanner et al., 1972). Indeed, in Szatmari et al. (1989), all children retrospectively judged as only probable for a diagnosis of autism had poor outcomes as adults, while many children whose diagnosis – according to the strictest criteria for autism ever devised – was not in doubt went on to considerable achievement: "severity of early autistic behavior was a poor predictor of outcome" (p. 213).

Early interventions have been widely speculated both to prevent atypical brain activity in autism and to promote desirable typical activity (e.g., Lovaas and Smith, 1989; Perry et al., 1995; Mundy and Crowson, 1997; Smith and Lovaas, 1998; Howard et al., 2005). This speculation is as yet unsupported by studies involving measures of neural activity. The promotion of very early interventions to exploit neural plasticity in the developing brain (Dawson and Zanolli, 2003) appears to be supported solely by a report of a very early (starting at 14 months) applied behavior analysis-based intervention involving a child considered 'at risk' for autism (Green et al., 2002). However, such a young age (2 years) has been cited as an explanation for why other autistic participants failed, rather than succeeded, in another intervention study and why such young participants could not continue in an optimal applied behavior analysis-based intervention (Howard et al., 2005). Thus, promises that autistic brain activity and development can be altered by early interventions in controlled and predictable ways appear to be highly premature.

Training programs that involve older autistics (school-aged children, adolescents, and adults) and that target what are presumed to be core deficits in autism have also been speculated to correct faulty autistic neural mechanisms (Tanaka et al., 2005). However, the only empirical investigation to date found that autistics acquired the specific trained behaviors (labeling pictures expressing facial affect), but did so without producing the desired neurofunctional changes (increased task-related activity in the fusiform gyrus; Bölte et al., 2006). Demonstrations that untrained autistics display this desired brain activity when previous oversights in experimental design are addressed (e.g., Hadjikhani et al., 2004; Pierce et al., 2004) raise questions about the foundations of interventions that target core deficits and exploit task-related brain activity as outcomes.

A common finding arising from both targeted and comprehensive intervention studies is that autistics, when explicitly taught typical skills, fail to generalize those skills across contexts or to related typical skills (e.g., Lovaas et al., 1973; Lovaas and Smith, 1989; Ozonoff and Miller, 1995; Hwang and Hughes, 2000). This failure to generalize is widely regarded as an autistic learning deficit, but such a failure cannot always be attributed to specifically autistic limitations. Young so-called feminine boys who underwent early intensive behavioral interventions to impose stereotypically male behaviors also demonstrated a failure to generalize (Rekers and Lovaas, 1974; Rekers et al., 1974). Thus, the explicit teaching of typical behaviors may result in a failure to generalize in atypical individuals. Accordingly, autistics who fully understand typical, expected social behaviors (e.g., behaviors associated with pretend play or joint attention) may not spontaneously display these behaviors, which are adaptive for nonautistics but may not necessarily be adaptive for autistics (e.g., Boucher, 1989; Klin et al., 2002). Regulation of atypical autistic visual and auditory perception (Mottron et al., 2006; Samson et al., 2006) is currently the most plausible explanation for characteristic autistic behaviors (e.g., in the areas of eye contact, Gernsbacher and Frymiare, 2005; joint attention, Gernsbacher et al., in press; and orienting to stimuli, Mottron et al., 2007); therefore, attempts to train typical but less adaptive behaviors may not easily generalize. Further, Szatmari (2004) has argued that autistics' enhanced perception results in independent, spontaneous learning of which nonautistics are incapable.

## 2.39.5 Applied Behavior Analysis and Autistic Learning

The first reports of operant conditioning in autism in the early 1960s (e.g., Ferster and DeMyer, 1961) are considered by behavior analysts as the first demonstrations that autistics could learn (Schreibman and Ingersoll, 2005). Behavior analysts henceforth characterized autistics as being governed by the same laws of learning as all other organisms, while being distinguished by failing to learn from the typical, everyday environment (e.g., Lovaas, 1987; Green, 1996; Smith and Lovaas, 1998; Koegel et al., 2001; Lovaas and Smith, 2003). Applied behavior analysis (ABA), summarized by Green (1996: 29) as employing procedures derived from the principles of behavior to "build socially useful repertoires" of observable behaviors and reduce or extinguish socially "problematic ones," has become the basis for an extensive autism intervention literature and service industry. The behavior analytic literature in autism presents autistics as having an extremely restricted behavioral repertoire that is not recognizably human, as lacking in human experience to the point of being *tabula rasa*, as requiring the explicit teaching of virtually every human behavior, and therefore as being an ideal proving ground for interventions based on learning theory (Lovaas et al., 1967; Lovaas and Newsom, 1976; Lovaas, 1977, 1993, 2003; Lovaas and Smith, 1989; Smith, 1999; Schreibman, 2005).

Stimulus overselectivity, wherein autistics "respond to only part of a relevant cue, or even to a minor, often irrelevant feature of the environment," has been identified by behavior analysts as underlying autistics' failure to learn and generalize (Lovaas et al., 1979: 1237; see also Schreibman, 1996). However, demonstrations of overselectivity in autistics (e.g., Lovaas et al., 1971b; Lovaas and Schreibman, 1971) exist alongside findings showing overselectivity in nonautistics, as well as the absence of overselectivity in autistics (e.g., Koegel and Wilhelm, 1973; Schover and Newsom, 1976; Litrownick et al., 1978; Gersten, 1983). An apparent failure of autistics to attend to and therefore learn from relevant social information using dolls as stimuli (Schreibman and Lovaas, 1973) contrasts with the empirical finding that autistic children (IQ ~60) perform better than age-matched typical controls in recognizing their classmates' faces (Langdell, 1978). Moreover, Lovaas and Schreibman's (1971) and Lovaas et al.'s (1979) overselectivity-based prediction that classical conditioning would be impaired in autism, with a consequent failure to acquire conditioned reinforcers, was found to be incorrect. In a classical eyeblink conditioning paradigm, autistics more rapidly learned an association between multimodal contiguous stimuli than did nonautistics (Sears et al., 1994). Regardless, overselectivity's enduring theoretical influence is demonstrated in the behavior analytic practice of breaking all skills down into small steps with each step being explicitly taught through repetition, and of minimizing and simplifying the information in an autistic's environment when teaching basic skills (Maurice et al., 1996; Leaf and McEachin, 1999; Lovaas, 2003).

The need to suppress the high prevalence of so-called self-stimulatory behaviors in autistics (e.g., rocking the torso, smelling objects) is a consistent theme across the behavior analytic literature. While it is believed that self-stimulatory behaviors interfere with learning explicitly taught behaviors (e.g., Lovaas et al., 1971a, 1987; Koegel and Covert, 1971), that is not always the case (e.g., Klier and Harris, 1977; Chock and Glahn, 1983; Dyer, 1987), and self-stimulatory interests (e.g., maps, calendars, movies) have also been used productively as reinforcement (e.g., Charlop et al., 1990). Self-stimulatory behaviors have not been consistently defined by behavior analysts; for example, immediate echolalia (repeating back what another person just said) was classified as self-stimulatory in one model (Epstein et al., 1985; Lovaas, 2003) but not in another (Gardenier et al., 2004; MacDonald et al., 2007).

Self-stimulatory behaviors are often defined as serving no obvious or apparent function (Gardenier et al., 2004; MacDonald et al., 2007), but in one extensive behavior analysis to understand the origin of self-stimulatory "ear covering that was reported by the [autistic] child's teachers to serve no identifiable function" the "[r]esults of a descriptive analysis revealed a correlation between ear covering and another child's screaming. An analog functional analysis showed that ear covering was emitted only when the screaming was present" (Tang et al., 2002: 95).

While self-stimulation has been defined as a subclass of stereotypy, characterized by its autonomy from social reinforcement (Lovaas et al., 1987), it has also been found to be socially mediated (Durand and Carr, 1987). Self-stimulation and stereotypy are sometimes regarded as interchangeable (e.g., Charlop-Christy and Haymes, 1996, in which 'stereotypy,' 'aberrant behaviors,' 'obsessions,' and 'self-stimulation' are equivalent terms), and self-stimulatory behaviors have been expanded to encompass all autistic focused interests and abilities. Absolute pitch, calendar calculation, hyperlexia, expertise in prime numbers, accurate drawing, and the like have been classified as self-stimulatory (Epstein et al., 1985; Lovaas, 2003); autistics' spontaneous, untrained learning (in the absence of either teaching or reinforcement) has been classified as "generative self-stimulatory behavior" (Lovaas et al., 1987: 58). Epstein et al. (1985) described a 5-year-old autistic boy in an intensive ABA program who "suddenly emerged" (p. 292) with excellent calendar calculation skills; this and other spontaneous 'genius' behaviors were then discouraged and suppressed.

Indeed, exceptional and savant abilities are listed by behavior analysts as among autistics' abnormal behavioral deficits and excesses (e.g., Koegel and Koegel, 1995). Exceptional abilities in children who exhibit high levels of self-stimulatory behaviors, which are considered by behavior analysts to prevent autistics from learning, remain unexplained. For example, there is no explanation for how a 3-year-old autistic "engaged in lengthy periods of self-stimulatory behavior, such as lying down and sifting sand through his hands" learned to read at a grade 1 level (Koegel et al., 1997: 236), or how a 4-year-old autistic, with no basal score on standardized language measures and "high levels" of "stereotypic hand flapping, finger manipulation, body rocking and noise making" learned how to "decode written words" and "discriminate numerous varieties of automobiles" (Mason et al., 1989: 173). The behavior analytic observation that autistics have spontaneously learned various skills that they do not demonstrate on demand (e.g., Taylor and MacDonough, 1996) also remains unexplained, though the possibility that autistics' inconsistent responding in some situations results from 'boredom' has been raised (Dunlap and Koegel, 1980).

In attempting to address autistics' failure to learn, behavior analysts have created environments of extreme food deprivation (Lovaas et al., 1967); electric shock (Lichstein and Schreibman, 1976) or other contingent aversives (Lovaas, 1987; Lovaas et al., 1987); and extreme repetition (e.g., 90 000 discrete trials to teach an autistic boy one verbal discrimination; Lovaas, 1977). One autistic child underwent more than 24 000 discrete trials and failed to learn any receptive language (Eikeseth and Jahr, 2001). The same child acquired language skills in fewer than 100 trials when provided with text, rather than speech or signs, but environments created by behavior analysts to train some autistics (now deemed to be 'visual learners') with text have produced very limited results (Lovaas and Eikeseth, 2003). While physical punishment within behavior interventions became illegal in many jurisdictions and was replaced by other methods (but see Foxx, 2005), a nonrandomized controlled trial that depended on contingent aversives (Lovaas, 1987; McEachin et al., 1993) continues to be cited as the primary evidence that ABA-based interventions are effective. The only randomized controlled trial of an early comprehensive ABA program reported poor short-term results (Smith et al., 2000, 2001). When unmatched variables in a nonrandomized trial were accounted for, differences in outcome measures between the experimental and control groups (with the exception of classroom placement) were not significant (Cohen et al., 2006; see also Magiati et al., 2007). Further, none of the few existing small-sample controlled trials, in a vast literature dominated by single-subject designs, has reported a correlation between increased amount or intensity of treatment and better short-term outcome measures. Instead, data from an uncontrolled trial show that neither intensity nor quality of early ABA programs is related to short-term outcomes (Sallows and Graupner, 2005).

## 2.39.6 Autistic Learning in the Cognitive and Savant Literatures

The cognitive literature in autism provides few empirical findings directly related to learning, despite speculative claims about autistic learning impairments and 'learning style' (see Volkmar, et al., 2004, for a review). Among empirical findings, autistics have demonstrated enhanced discrimination of novel highly similar stimuli but an absence of a typical perceptual learning effect (Plaisted et al., 1998); and nonautistics, but not autistics, showed a training effect when copying drawings of objects and nonobjects, although overall performance of the two groups was equal (Mottron et al., 1999). In both cases (perception and procedural memory), procedures (e.g., repeated performance of tasks) that reliably resulted in learning in nonautistics appeared not to do so in autistics, while autistics appeared to learn in ways (e.g., apparently passive exposure to materials) that did not necessarily benefit nonautistics.

In the area of language, echolalia is common in typical development (e.g., a mother asks, 'Do you want a cookie?' and a child responds, 'a cookie?'), but echolalia occupies an atypical role in language acquisition in autism. Echolalia, which serves numerous functions (Prizant and Duchan, 1981; Prizant, 1983; Prizant and Rydell, 1984), is one example of how autistics atypically access the meaning of language by first learning its complex structure, the reverse of the typical pattern (Dunn and Sebastian, 2000). For example, an autistic child, quite fond of the Teletubbies show on Public Broadcasting Service, initially repeated the scripted sentence, "One day in Teletubbie land, all of the Teletubbies were very busy when suddenly a big rain cloud appeared," and weeks later, using mitigated echolalia, stated, "One day in Bud's house, Mama and Bud were very busy when suddenly Daddy appeared" to express the construct of his father returning home. Initially, when this child wanted to play ball, he would approach his mother or father and say, "Quick, Dipsy. Help Laa Laa catch the ball." As his spoken language developed, the syntactic structure of echolalic sentences remained intact, but he replaced the nouns (e.g., "Quick, Daddy. Help Bud catch the ball"), and he eventually isolated single words and morphemes and began generating original phrases (e.g., "Daddy ball?" and "Dad, wanna play ball?"; Mom-NOS, 2006).

Hyperlexia (Silverberg and Silverberg, 1967), a spontaneous (uninstructed), precocious, interest-driven ability to decode written words, is also strongly associated with autism (Grigorenko et al., 2002). Atkin and Lorch (2006) extensively tested Paul, a 4-year-old autistic boy who intensively studied newspapers before age 2 and recited the alphabet and read printed words aloud by age 3. Paul's mental age was placed at 1 year and 5 months, and his comprehension of language was markedly delayed (though not absent), but he tested as having "extremely advanced decoding skills" (p. 266), including a reading vocabulary exceeding that of typical 9-year-olds. The authors concluded that these results "suggest the possibility of an atypical route to language acquisition" (p. 267) and that "existing cognitive accounts are inadequate to account for the development of literacy in this child" (p. 267).

With respect to the role of categories in learning, autistics may not necessarily use concepts to organize information (Hermelin and O'Connor, 1970; Bowler, 2007, for a review), but are able to do so, including the use of basic level and more abstract superordinate categories as well as prototypes (e.g., Tager-Flusberg, 1985a,b; Ungerer and Sigman, 1987). In a test of novel category learning, Klinger and Dawson (2001) found that autistics categorized using both explicit and implicit rules, but when answering an ambiguous question, failed to show the same response to prototypes as nonautistics. Molesworth et al. (2005), who instead used a false recognition procedure, found typical learning of novel categories in autistics, including typical prototype formation. At the level of perceptual categorization, autistics demonstrated typical category formation in a categorization task, but in contrast to typical controls, autistics showed no influence of categories in a discrimination task. The influence of categories may therefore be optional in autistics, while being mandatory in nonautistics (Soulières et al., 2007).

Klinger et al. (2006) have proposed a fundamental implicit learning (Reber, 1967, 1993; Frensch, 1998; Frensch and Rünger, 2003) impairment in autism based on the prototype paradigm in Klinger and Dawson (2001) and on preliminary data from two artificial grammar learning experiments. Their first study found equivalent autistic and nonautistic above-chance performance in the implicit learning of artificial grammars, while in their second study autistics with lower IQs than their nonautistic controls performed far above chance, but the nonautistic group performed significantly better. Reber (1967) reported a similar discrepancy between typical undergraduates and typical high-school students performing well above chance, without the latter being deemed impaired in implicit learning. Using a serial reaction time task (Nissen and Bullemer, 1987) involving a sequence of lighted circles, Mostofsky et al. (2000) found no evidence of implicit learning in autistics. However, using the same kind of task, Smith (2003) found robust implicit learning of a sequence of geometric figures in autistics, with response accuracy superior to that of typical controls. Results from Smith's (2003) second experiment using a sequence of emotional face images suggest that the presence of social information may demand more attentional resources from autistics than nonautistics, therefore disproportionately interfering with autistics' implicit learning of nonsocial material (in this case, a sequence).

Associative learning has been reported as intact in autism (e.g., Boucher and Warrington, 1976; Williams et al., 2006), but autistics were also found to associate paired stimuli more rapidly than nonautistics (Sears et al., 1994). Reviewing a wide range of evidence, Baron-Cohen (2003) posited systemizing, a form of intrinsically reinforced associative learning, as being a strength in autism, "a condition where unusual talents abound" (p. 138). Systemizing requires an exact mind and is motivated not by extrinsic reinforcement but by a drive to understand systems. Baron-Cohen (2003) describes an autistic 5-year-old boy whose mother accidentally discovered that, by walking down the same street every day, he had correctly associated hundreds of houses with the hundreds of cars (parked on the street) of their occupants, along with the expiration dates and serial numbers of the cars' parking stickers.

In contrast, Tomasello et al. (1993, 2005; see also Tomasello, 2001) posited a form of social learning – cultural learning – as the defining achievement of uniquely human cognitive abilities, which autistics, along with apes, were deemed to lack. However, despite claims that the essential uniquely human ability is the learning of intentionality, which according to Tomasello autistics lack (Tomasello et al., 1993; Tomasello, 2001), empirical studies have demonstrated robust understanding of intentions in autistic children (Aldridge et al., 2000; Carpenter et al., 2001; Russell and Hill, 2001) and adults (Sebanz et al., 2005). The current model of cultural learning and cognition (Tomasello et al., 2005) is now founded not on the learning but the sharing of intentionality, which Tomasello has argued is absent in autistics and apes. The defining of humanity according to attributes that autistics are judged to lack is a hallmark of normocentrism (Mottron et al., in press).

After a long history of reductive explanations for savant abilities (e.g., photographic or phonographic memory), the savant literature largely recognizes that these abilities represent both spontaneous learning and creative manipulation of the structures and regularities underlying complex information (e.g., music, numbers, written language, visual proportions and perspective). Experimental studies of savants have concentrated on whether and how learned information and abilities are recalled, applied, modified, transformed, or transferred (Miller, 1999; Heaton and Wallace, 2004). Therefore, while savant abilities in autistics can be considered the equivalent of expertise in nonautistics (Mottron et al., 2006), there is only indirect evidence as to how this expertise is acquired. Overtraining with specific materials may (Howe et al., 1998) or may not (e.g., Selfe, 1977; Epstein et al., 1985) be observed prior to the full manifestation of exceptional abilities, which may also be discovered by accident (Sacks, 1985).

Thioux et al. (2006) proposed that savant abilities are driven by autistic focused interests, but depend on spared areas of typical learning abilities; in this model, as in Klinger et al. (2006), savant abilities are explicitly learned, with no role for implicit learning. However, implicit learning is widely considered to play an essential role in savant abilities (e.g., Hermelin and O'Connor, 1986; O'Connor, 1989; Miller, 1989, 1999; Spitz, 1995; Heaton and Wallace, 2004; Pring, 2005; Mottron et al., 2006). Miller (1999) has related the sophistication found in savant abilities to both enhanced processing at the perceptual level and the implicit learning of regularities, while suggesting that extensive exposure to materials may, for savants, be more effective than typical forms of teaching or rehearsal, which in turn may impede learning in savants. He concluded that "savants may provide a special perspective on the mixture of implicit and explicit learning that produces noteworthy performance" (p. 43).

Treffert (2000) has argued that savant abilities should be encouraged and nurtured; this results in a broadening of focused abilities and the flourishing of previously limited social abilities. For example, Miller (1989) denies that a young musical savant could be autistic, regardless of his fitting the relevant criteria, on the grounds that by age 5, he "showed obvious pleasure in social interaction" (p. 10). However, prior to the availability of a piano, the same boy was described as "not very responsive" (p. 9), "spending hour after hour gazing out the window" (p. 210), and "for a very long time, nonverbal and withdrawn" (Newman, 1989: 239). Further, autism does not preclude pleasure in social interaction, which for example is observed in autistics spontaneously sharing the same interest with each other (LeGoff, 2004).

Savant and nonsavant autistics are best considered as belonging to the same group, based on multiple behavioral and cognitive similarities. The performance of savants predicts the performance of nonsavant autistics in multiple areas. For example, savant musicians invariably have absolute pitch, while absolute pitch (Brown et al., 2003) and superior pitch labeling, pitch memory (Heaton et al., 1998; Heaton, 2003), and pitch discrimination and categorization (Bonnel et al., 2003) characterize nonsavant autistics. In a music imitation task, nonsavant autistic youths (mean IQ <70) with no musical experience performed as well as or better than age-matched controls who had considerable musical training (Applebaum et al., 1979), echoing the superior musical imitation found in savant autistics (e.g., Slodoba et al., 1985; Young and Nettlebeck, 1995). A savant draftsman (Mottron and Belleville, 1993) and nonsavant autistics (Mottron et al., 1999) shared a facility in copying impossible figures and a recognizable, locally oriented drawing strategy. Savant (Park, 1986; Steel et al., 1984; Hermelin and O'Connor, 1990; Young and Nettlebeck, 1995; Anderson et al., 1999) and nonsavant (Scheuffgen, 2000; Dawson et al., 2007) autistics may present with exceptional performance in tests of processing speed and/or high-level abstract reasoning. Many other empirically documented similarities are available, but it is also true that regardless of being extensively studied, both autism and savant syndrome remain unexplained. So does the overlapping relationship between the two, along with the learning processes underlying both variations in neurological functioning and information analysis.

## 2.39.7 Summary: Characterizing Autistic Learning

Learning in autism is characterized both by spontaneous – sometimes exceptional – mastering of complex material and an apparent resistance to learning in conventional ways. Learning that appears to be implicit seems to be important in autism, but autistics' implicit learning may not map directly onto nonautistics' implicit learning or be governed by the same constraints. An understanding of autistic learning, of how and why autistics learn well and learn poorly, may therefore require a nonnormocentric approach and an investigation of the possibility that autistic and nonautistic cognition may be complementary in learning and advancing different aspects of knowledge.

## References


Aldridge MA, Stone KR, Sweeney MH, and Bower TGR (2000) Preverbal children with autism understand the intentions of others. *Dev. Sci.* 3: 294–301.

American Psychiatric Association (1994) *Diagnostic and Statistical Manual of Mental Disorders,* 4th edn. Washington, DC: American Psychological Association.

Anderson M, O'Connor N, and Hermelin B (1999) A specific calculating ability. *Intelligence* 26: 383–403.

Applebaum E, Egel AL, Koegel RL, and Imhoff B (1979) Measuring musical abilities of autistic children. *J. Autism Dev. Disord.* 9: 279–285.

Asperger H (1944/1991) 'Autistic psychopathology' in childhood, Frith U (trans.). In: Frith U (ed.) *Autism and Asperger Syndrome*, pp. 37–92. Cambridge: Cambridge University Press.

Atkin K and Lorch M (2006) Hyperlexia in a 4-year-old boy with autistic spectrum disorder. *J. Neurolinguistics* 19: 253–269.

Baird G, Charman T, Baron-Cohen S, et al. (2000) A screening instrument for autism at 18 months of age: A 6-year follow-up study. *J. Am. Acad. Child. Adolesc. Psychiatry* 39: 694–702.

Baron-Cohen S (2003) *The Essential Difference: Male and Female Brains and the Truth about Autism*. New York: Basic.

Baron-Cohen S (2005) Enhanced attention to detail and hyper-systemizing in autism. Commentary on Milne E, Swettenham J, Campbell R, Motion perception and autistic spectrum disorder: A review. *Current Psychol. Cogn.* 23: 59–64.

Battaglia A and Carey JC (2006) Etiologic yield of autistic spectrum disorders: A prospective study. *Am. J. Med. Genet. C Semin. Med. Genet.* 142: 3–7.

Beversdorf DQ, Smith BW, Crucian GP, et al. (2000) Increased discrimination of "false memories" in autism spectrum disorder. *Proc. Natl. Acad. Sci. USA* 97: 8734–8737.

Bölte S, Hubl D, Feineis-Matthews S, et al. (2006) Facial affect recognition training in autism: Can we animate the fusiform gyrus? *Behav. Neurosci.* 120: 211–216.

Bonnel A, Mottron L, and Peretz I, et al. (2003) Enhanced pitch sensitivity in individuals with autism: A signal detection analysis. *J. Cogn. Neurosci.* 15: 226–235.

Boucher J (1989) The theory of mind hypothesis of autism: Explanation, evidence and assessment. *Br. J. Disord. Commun.* 24: 181–198.

Boucher J and Warrington EK (1976) Memory deficits in early infantile autism: Some similarities to the amnesic syndrome. *Br. J. Psychol.* 67: 73–87.

Bowler D (2007) *Autism Spectrum Disorders: Psychological Theory and Research*. Hove, UK: Wiley.

Brown WA, Cammuso K, Sachs H, et al. (2003) Autism-related language, personality, and cognition in people with absolute pitch: Results of a preliminary study. *J. Autism Dev. Disord.* 33: 163–167.

Carpenter M, Pennington BF, and Rogers SJ (2001) Understanding of others' intentions in children with autism. *J. Autism Dev. Disord.* 31: 589–599.

Casanova MF, Buxhoeveden DP, Switala AE, and Roy E (2002) Minicolumnar pathology in autism. *Neurology* 58: 428–432.

Cecil S (2004) Autism interrupted? Baby sibs study holds hope for reversing behaviors before they become embedded. *CAIRN Rev.* 1: 2.

Chakrabarti S and Fombonne E (2001) Pervasive developmental disorders in preschool children. *JAMA* 285: 3093–3099.

Chakrabarti S and Fombonne E (2005) Pervasive developmental disorders in preschool children: Confirmation of high prevalence. *Am. J. Psychiatry* 162: 1133–1141.

Charlop MH, Kurtz PF, and Casey FG (1990) Using aberrant behaviors as reinforcers for autistic children. *J. Appl. Behav. Anal.* 23: 163–181.

Charlop-Christy MH and Haymes LK (1996) Using obsessions as reinforcers with and without mild reductive procedures to decrease inappropriate behaviors of children with autism. *J. Autism Dev. Disord.* 26: 527–546.

Chawarska K, Klin A, and Volkmar F (2003) Automatic attention cueing through eye movement in 2-year-old children with autism. *Child Dev.* 74: 1108–1122.

Chock PN and Glahn TJ (1983) Learning and self-stimulation in mute and echolalic autistic children. *J. Autism Dev. Disord.* 13: 365–381.

Cohen H, Amerine-Dickens M, and Smith T (2006) Early intensive behavioral treatment: Replication of the UCLA model in a community setting. *J. Dev. Behav. Pediatr.* 27: S145–S155.

Dawson G and Osterling J (1997) Early intervention in autism: Effectiveness and common elements of current approaches. In: Guralnick MJ (ed.) *The Effectiveness of Early Intervention: Second Generation Research*, pp. 307–326. Baltimore: Brookes.

Dawson G and Zanolli K (2003) Early intervention and brain plasticity in autism. In: Bock G and Goode J (eds.) *Autism: Neural Bases and Treatment Possibilities*, pp. 266–280. Chichester, UK: John Wiley.

Dawson M, Soulières I, Gernsbacher MA, and Mottron L (2007) The level and nature of autistic intelligence. *Psychol. Sci.* 18: 657–662.

DeMyer MK, Barton S, DeMyer WE, et al. (1973) Prognosis in autism: A follow-up study. *J. Autism Child. Schizophr.* 3: 199–246.
DeMyer MK, Barton S, Alpern GD, et al. (1974) The measured intelligence of autistic children. *J. Autism Child. Schizophr.* 4: 42–60.
Dunlap G and Koegel RL (1980) Motivating autistic children through stimulus variation. *J. Appl. Behav. Anal.* 13: 619–627.
Dunn M and Sebastian MJ (2000) A neuropsychological approach to language intervention in autistic children. In: Accardo PJ, Magnusen C, and Capute AJ (eds.) *Autism: Clinical and Research Issues*, pp. 57–75. Baltimore: York Press.
Durand VM and Carr EG (1987) Social influences on ''self-stimulatory'' behavior: Analysis and treatment application. *J. Appl. Behav. Anal.* 20: 119–132.
Dyer K (1987) The competition of autistic stereotyped behavior with usual and specially assessed reinforcers. *Res. Dev. Disabil.* 8: 607–626.
Eaves LC and Ho HH (2004) The very early identification of autism: Outcome to age 4 1/2–5. *J. Autism Dev. Disord.* 34: 367–378.
Eikeseth S and Jahr E (2001) The UCLA reading and writing program: An evaluation of the beginning stages. *Res. Dev. Disabil.* 22: 289–307.
Epstein LJ, Taubman MT, and Lovaas OI (1985) Changes in self-stimulatory behaviors with treatment. *J. Abnorm. Child Psychol.* 13: 281–293.
Ferster CB and DeMyer MK (1961) The development of performances in autistic children in an automatically controlled environment. *J. Chronic Dis.* 13: 312–345.
Foxx RM (2005) Severe aggressive and self-destructive behavior: The myth of nonaversive treatment of severe behavior. In: Jacobson JW, Foxx RM, and Mulick JA (eds.) *Controversial Therapies for Developmental Disabilities*, pp. 295–310. Mahwah, NJ: Lawrence Erlbaum Associates.
Frensch PA (1998) One concept, multiple meanings: On how to define the concept of implicit learning. In: Stadler MA and Frensch PA (eds.) *Handbook of Implicit Learning*, pp. 47–104. Thousand Oaks, CA: Sage.
Frensch PA and Rünger D (2003) Implicit learning. *Curr. Dir. Psychol. Sci.* 12: 13–18.
Gardenier NC, MacDonald R, and Green G (2004) Comparison of direct observational methods for measuring stereotypic behavior in children with autism spectrum disorders. *Res. Dev. Disabil.* 25: 99–118.
Gernsbacher MA (2003) Is one style of early behavioral treatment for autism 'scientifically proven'? *J. Dev. Learning Disord.* 7: 19–25.
Gernsbacher MA (2004) Language without speech: A case study. *J. Dev. Learning Disord.* 8: 123–138.
Gernsbacher MA and Frymiare JL (2005) Does the autistic brain lack core modules? *J. Dev. Learning Disord.* 9: 3–16.
Gernsbacher MA, Dawson M, and Mottron L (2006) Autism: Common, heritable, but not harmful. *Behav. Brain. Sci.* 29: 413–414.
Gernsbacher MA, Stevenson JL, Khandakar S, Goldsmith HH (in press) Why is joint attention atypical in autism? *Child Dev. Perspect*.
Gersten R (1983) Stimulus overselectivity in autistic, trainable mentally retarded, and non-handicapped children: Comparative research controlling chronological (rather than mental) age. *J. Abnorm. Child Psychol.* 11: 61–75.
Green G (1996) Early behavioral intervention for autism: What does research tell us? In: Maurice C, Green G, and Luce SC (eds.) *Behavioral Intervention for Young Children with Autism: A Manual for Parents and Professionals*, pp. 29–44. Austin, TX: Pro-Ed.
Green G (1999) Science and ethics in early intervention for autism. In: Ghezzi PM, Williams WL, and Carr JE (eds.) *Autism: Behavior Analytic Perspectives*, pp. 11–28. Reno: Context Press.
Green G, Brennan LC, and Fein D (2002) Intensive behavioral treatment for a toddler at high risk for autism. *Behav. Modif.* 26: 69–102.
Grigorenko EL, Klin A, Pauls DL, et al. (2002) A descriptive study of hyperlexia in a clinically referred sample of children with developmental delays. *J. Autism Dev. Disord.* 32: 3–12.
Hadjikhani N, Joseph RM, Snyder J, et al. (2004) Activation of the fusiform gyrus when individuals with autism spectrum disorder view faces. *Neuroimage* 22: 1141–1150.
Handleman JS and Harris SL (eds.) (2001) *Preschool Education Programs for Children with Autism*. Austin, TX: Pro-Ed.
Hazlett HC, Poe M, Gerig G, et al. (2005) Magnetic resonance imaging and head circumference study of brain size in autism: Birth through age 2 years. *Arch. Gen. Psychiatry* 62: 1366–1376.
Heaton P (2003) Pitch memory, labeling and disembedding in autism. *J. Child Psychol. Psychiatry* 44: 543–51.
Heaton P and Wallace GL (2004) Annotation: The savant syndrome. *J. Child Psychol. Psychiatry* 45: 899–911.
Heaton P, Hermelin B, and Pring L (1998) Autism and pitch processing: A precursor for savant musical ability? *Music Percept.* 15: 291–305.
Hermelin B and O'Connor N (1970) *Psychological Experiments with Autistic Children*. Oxford: Pergamon Press.
Hermelin B and O'Connor N (1986) Idiot savant calendrical calculators: Rules and regularities. *Psychol. Med.* 16: 885–893.
Hermelin B and O'Connor N (1990) Factors and primes: A specific numerical ability. *Psychol. Med.* 20: 163–169.
Hill AL (1977) Idiot savants: Rate of incidence. *Percept. Mot. Skills* 44: 161–162.
Honda H, Shimizu Y, Misumi K, Niimi M, and Ohashi Y (1996) Cumulative incidence and prevalence of childhood autism in Japan. *Br. J. Psychiatry* 169: 228–235.
Howard JS, Sparkman CR, Cohen HG, Green G, and Stanislaw H (2005) A comparison of intensive behavior analytic and eclectic treatments for young children with autism. *Res. Dev. Disabil.* 26: 359–383.
Howe MJA, Davidson JW, and Sloboda JA (1998) Innate talents: Reality or myth? *Behav. Brain Sci.* 21: 399–407.
Howlin P (2005) Outcomes in autism spectrum disorders. In: Volkmar FR, Paul R, Klin A, and Cohen D (eds.) *Handbook of Autism and Pervasive Developmental Disorders*, pp. 201–220. Hoboken, NJ: Wiley.
Hwang B and Hughes C (2000) The effect of social interactive training on early social communicative skills of children with autism. *J. Autism Dev. Dis.* 30: 331–343.
Just MA, Cherkassky VL, Keller TA, and Minshew NJ (2004) Cortical activation and synchronization during sentence comprehension in high-functioning autism: Evidence of underconnectivity. *Brain* 127: 1811–1821.
Kanner L (1943) Autistic disturbances of affective contact. *Nerv. Child* 2: 217–250.
Kanner L (1949) Problems of nosology and psychodynamics in early infantile autism. *Am. J. Orthopsychiatry* 19: 416–426.
Kanner L (1951) The conception of wholes and parts in early infantile autism. *Am. J. Psychiatry* 108: 23–26.
Kanner L (1971) Follow-up study of eleven autistic children originally reported in 1943. *J. Autism Child. Schizophr.* 1: 119–145.
Kanner L (1973) *Childhood Psychosis: Initial Studies and New Insights*. New York: Winston/Wiley.
Kanner L and Eisenberg L (1956/1973) Notes on the follow-up studies of autistic children. In: Kanner L (ed.) *Childhood*

*Psychosis: Initial Studies and New Insights*, pp. 77–89. New York: Winston/Wiley.
Kanner L, Rodriguez A, and Ashenden B (1972) How far can autistic children go in matters of social adaptation? *J. Autism Child. Schizophr.* 2: 9–33.
Kasari C (2006) What are the active ingredients of interventions? Presented at the International Meeting for Autism Research. Montreal, Canada, June 2006.
Kielinen M, Linna SL, and Moilanen I (2000) Autism in Northern Finland. *Eur. Child Adolesc. Psychiatry* 9: 162–167.
Klier J and Harris SL (1977) Self-stimulation and learning in autistic children: Physical or functional incompatibility? *J. Appl. Behav. Anal.* 10: 311.
Klin A, Carter A, and Sparrow S (1997) Developmentally-based assessments: Psychological assessment. In: Cohen DJ and Volkmar FR (eds.) *Handbook of Autism and Pervasive Developmental Disorders*, pp. 418–427. New York: Wiley.
Klin A, Jones W, Schultz R, Volkmar F, and Cohen D (2002) Defining and quantifying the social phenotype in autism. *Am. J. Psychiatry* 159: 895–908.
Klinger LG and Dawson G (2001) Prototype formation in autism. *Dev. Psychopathol.* 13: 111–124.
Klinger LG, Klinger MR, and Pohlig R (2006) Implicit learning impairments in autism spectrum disorders: Implications for treatment. In: Perez JM, Gonzalez PM, Comi ML, and Nieto C (eds.) *New Developments in Autism: The Future is Today*, pp. 75–102. London: Jessica Kingsley.
Koegel LK and Koegel RL (1995) Motivating communication in children with autism. In: Schopler E and Mesibov GB (eds.) *Learning and Cognition in Autism*, pp. 73–87. New York: Plenum.
Koegel LK, Koegel RL, and Smith A (1997) Variables related to differences in standardized test outcomes for children with autism. *J. Autism Dev. Disord.* 27: 233–43.
Koegel RL and Covert A (1972) The relationship of self-stimulation to learning in autistic children. *J. Appl. Behav. Anal.* 5: 381–387.
Koegel RL and Wilhelm H (1973) Selective responding to the components of multiple visual cues by autistic children. *J. Exp. Child Psychol.* 15: 442–453.
Koegel RL, Koegel LK, and McNerney EK (2001) Pivotal areas in intervention for autism. *J. Clin. Child Psychol.* 30: 19–32.
Koshino H, Carpenter PA, Minshew NJ, et al. (2005) Functional connectivity in an fMRI working memory task in high-functioning autism. *Neuroimage* 24: 810–821.
Langdell T (1978) Recognition of faces: An approach to the study of autism. *J. Child Psychol. Psychiatry* 19: 255–268.
Leaf RB and McEachin J (1999) *A Work in Progress: Behavior Management Strategies and a Curriculum for Intensive Behavioral Treatment of Autism*. New York: DRL Books.
LeGoff DB (2004) Use of LEGO© as a therapeutic medium for improving social competence. *J. Autism Dev. Disord.* 34: 557–571.
Lichstein KL and Schreibman L (1976) Employing electric shock with autistic children: A review of the side effects. *J. Autism Child Schizophr.* 6: 163–173.
Litrownik AJ, McInnis ET, Wetzel-Pritchard AM, and Filipelli DL (1978) Restricted stimulus control and inferred attentional deficits in autistic and retarded children. *J. Abnorm. Psychol.* 87: 554–562.
Lockyer L and Rutter M (1969) A five- to fifteen-year follow-up study of infantile psychosis. *Br. J. Psychiatry* 115: 865–882.
Lord C, Risi S, DiLavore PS, et al. (2006) Autism from 2 to 9 years of age. *Arch. Gen. Psychiatry* 63: 694–701.
Lovaas OI (1977) *The Autistic Child: Language Development Through Behavior Modification*. New York: Irvington.
Lovaas OI (1987) Behavioral treatment and normal educational and intellectual functioning in young autistic children. *J. Consult. Clin. Psychol.* 55: 3–9.
Lovaas OI (1993) The development of a treatment-research project for developmentally disabled and autistic children. *J. Appl. Behav. Anal.* 26: 617–630.
Lovaas OI (2003) *Teaching Individuals with Developmental Delays: Basic Intervention Techniques*. Austin, TX: Pro-Ed.
Lovaas NW and Eikeseth S (2003) Reading and writing: A brief introduction. In: Lovaas OI (ed.) *Teaching Individuals with Developmental Delays: Basic Intervention Techniques*, pp. 271–289. Austin, TX: Pro-Ed.
Lovaas OI and Newsom CD (1976) Behavior modification with psychotic children. In: Leitenberg H (ed.) *Handbook of Behavior Modification and Behavior Therapy*, pp. 303–360. Englewoood Cliffs, NJ: Prentice-Hall.
Lovaas OI and Schreibman L (1971) Stimulus overselectivity of autistic children in a two stimulus situation. *Behav. Res. Ther.* 9: 305–310.
Lovaas OI and Smith T (1989) A comprehensive behavioral theory of autistic children: Paradigm for research and treatment. *J. Behav. Ther. Exp. Psychiatry* 20: 17–29.
Lovaas OI and Smith T (2003) Early and intensive behavioral intervention in autism. In: Kazdin AE and Weisz JR (eds.) *Evidence-based Psychotherapies for Children and Adolescents*, pp. 325–340. New York: Guilford.
Lovaas OI, Freitas L, Nelson K, and Whalen C (1967) The establishment of imitation and its use for the development of complex behavior in schizophrenic children. *Behav. Res. Ther.* 5: 171–181.
Lovaas OI, Litrownik A, and Mann R (1971a) Response latencies to auditory stimuli in autistic children engaged in self-stimulatory behavior. *Behav. Res. Ther.* 9: 39–49.
Lovaas OI, Schreibman L, Koegel R, and Rehm R (1971b) Selective responding by autistic children to multiple sensory input. *J. Abnorm. Psychol.* 77: 211–222.
Lovaas OI, Koegel R, Simmons JQ, and Long JS (1973) Some generalization and follow-up measures on autistic children in behavior therapy. *J. Appl. Behav. Anal.* 6: 131–166.
Lovaas OI, Koegel RL, and Schreibman L (1979) Stimulus overselectivity in autism: A review of research. *Psychol. Bull.* 86: 1236–1254.
Lovaas I, Newsom C, and Hickman C (1987) Self-stimulatory behavior and perceptual reinforcement. *J. Appl. Behav. Anal.* 20: 45–68.
Macdonald R, Green G, Mansfield R, et al. (2007) Stereotypy in young children with autism and typically developing children. *Res. Dev. Disabil.* 28: 266–277.
Magiati I, Charman T, and Howlin P (2007) A two-year prospective follow-up study of community-based early intensive behavioural intervention and specialist nursery provision for children with autism spectrum disorders. *J. Child Psychol. Psychiatry* 48: 803–812.
Mason SA, McGee GG, Farmer-Dougan V, and Risley TR (1989) A practical strategy for ongoing reinforcer assessment. *J. Appl. Behav. Anal.,* 22: 171–177.
Maurice C, Green G, and Luce S (eds.) (1996) *Behavioral Intervention for Young Children with Autism: A Manual for Parents and Professionals*. Austin, TX: Pro-Ed.
McEachin JJ, Smith T, and Lovaas OI (1993) Long-term outcome for children with autism who received early intensive behavioral treatment. *Am. J. Ment. Retard.* 97: 359–372.
Miller LK (1989) *Musical Savants: Exceptional Skill in the Mentally Retarded*, Hillsdale, NJ: Erlbaum.
Miller LK (1999) The savant syndrome: Intellectual impairment and exceptional skill. *Psychol. Bull.* 125: 31–46.
Mom-NOS (2006) Dr. Strangetalk or: How I Learned to Stop Worrying and Love Echolalia. March 20 (2006) MOM: Not Otherwise Specified [online]. http://momnos.blogspot.com/

2006/03/dr-strangetalk-or-how-i-learned-to.html. Accessed 9 July 2007.
Molesworth CJ, Bowler DM, and Hampton JA (2005) The prototype effect in recognition memory: Intact in autism? *J. Child Psychol. Psychiatry* 46: 661–672.
Mostofsky SH, Goldberg MC, Landa RJ, and Denckla MB (2000) Evidence for a deficit in procedural learning in children and adolescents with autism: Implications for cerebellar contribution. *J. Int. Neuropsychol. Soc.* 6: 752–759.
Mottron L (2004) Matching strategies in cognitive research with individuals with high-functioning autism: Current practices, instrument biases, and recommendations. *J. Autism Dev. Disord.* 34: 19–27.
Mottron L and Belleville S (1993) A study of perceptual analysis in a high-level autistic subject with exceptional graphic abilities. *Brain Cogn.* 23: 279–309.
Mottron L, Belleville S, and Menard E (1999) Local bias in autistic subjects as evidenced by graphic tasks: Perceptual hierarchization or working memory deficit? *J. Child Psychol. Psychiatry* 40: 743–55.
Mottron L, Dawson M, Soulieres I, Hubert B, and Burack J (2006) Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *J. Autism Dev. Disord.* 36: 27–43.
Mottron L, Mineau S, Martel S, et al. (2007) Lateral glances toward moving stimuli among young children with autism: Early regulation of locally-oriented perception? *Dev. Psychopathol.* 19: 23–36.
Mottron L, Dawson M, and Soulieres I (in press) Another memory: About using distinctions built for non-autistics in describing autistic memory. In: Boucher J and Bowler D (eds.) *Memory in Autism.* Cambridge: Cambridge University Press.
Mundy P and Crowson M (1997) Joint attention and early social communication: Implications for research on intervention with autism. *J. Autism Dev. Disord.* 27: 653–676.
National Research Council (2001) *Educating Children with Autism. Committee on Educational Interventions for Children with Autism. Division of Behavioral and Social Sciences and Education*. Washington, DC: National Academy Press.
Newman (1989) A music teacher's perspective on savant skill. In: Miller LK (ed.) *Musical Savants: Exceptional Skill in the Mentally Retarded*, pp. 211–242. Hillsdale, NJ: Erlbaum.
Nissen MJ and Bullemer P (1987) Attentional requirements of learning: Evidence from performance measures. *Cognit. Psychol.* 19: 1–32.
O'Connor N (1989) The performance of the 'idiot-savant': Implicit and explicit. *Br. J. Disord. Commun.* 24: 1–20.
Ozonoff S and Miller JN (1995) Teaching theory of mind: A new approach to social skills training for individuals with autism. *J. Autism Dev. Disord.* 25: 415–433.
Park CC (1986) Social growth in autism: A parent's perspective. In: Schopler E and Mesibov GB (eds.) *Social Behavior in Autism*, pp. 81–99. New York: Plenum.
Pavone P, Incorpora G, Fiumara A, et al. (2004) Epilepsy is not a prominent feature of primary autism. *Neuropediatrics* 35: 207–210.
Perry R, Cohen I, and DeCarlo R (1995) Case study: Deterioration, autism, and recovery in two siblings. *J. Am. Acad. Child Adolesc. Psychiatry* 34: 232–237.
Pierce K, Haist F, Sedaghat F, and Courchesne E (2004) The brain response to personally familiar faces in autism: Findings of fusiform activity and beyond. *Brain* 127: 2703–2716.
Plaisted K, O'Riordan M, and Baron-Cohen S (1998) Enhanced discrimination of novel, highly similar stimuli by adults with autism during a perceptual learning task. *J. Child Psychol. Psychiatry* 39: 765–775.
Pring L (2005) Savant talent. *Dev. Med. Child Neurol.* 47: 500–503.
Prior MR (1979) Cognitive abilities and disabilities in infantile autism: A review. *J. Abnorm. Child Psychol.* 7: 357–380.
Prizant BM (1983) Language acquisition and communicative behavior in autism: Toward an understanding of the ''whole'' of it. *J. Speech. Hear. Disord.* 48: 296–307.
Prizant BM and Duchan JF (1981) The functions of immediate echolalia in autistic children. *J. Speech. Hear. Disord.* 46: 241–249.
Prizant BM and Rydell PJ (1984) Analysis of functions of delayed echolalia in autistic children. *J. Speech Hear. Res.* 27: 183–192.
Reber AS (1967) Implicit learning of artificial grammars. *J. Verbal. Learn. Verbal Behav.* 6: 855–863.
Reber AS (1993) *Implicit Learning and Tacit Knowledge: An Essay on the Cognitive Unconscious*. New York: Oxford University Press.
Rekers GA and Lovaas OI (1974) Behavioral treatment of deviant sex-role behaviors in a male child. *J. Appl. Behav. Anal.* 7: 173–190.
Rekers GA, Lovaas OI, and Low B (1974) The behavioral treatment of a ''transsexual'' preadolescent boy. *J. Abnorm. Child Psychol.* 2: 99–116.
Rimland B (1978) Savant capabilities of autistic children and their cognitive implications. In: Serban G (ed.) *Cognitive Defects in the Development of Mental Illness*, pp. 42–65. New York: Bruner/Mazel.
Rogers SJ and Ozonoff S (2006) Behavioral, educational and developmental treatments for autism. In: Moldin SO and Rubenstein JLR (eds.) *Understanding Autism: From Basic Neuroscience to Treatment*, pp. 443–473. Boca Raton, FL: Taylor & Francis.
Ropar D and Mitchell P (2002) Shape constancy in autism: The role of prior knowledge and perspective cues. *J. Child Psychol. Psychiatry* 43: 647–653.
Russell J and Hill E (2001) Action-monitoring and intention reporting in children with autism. *J. Child Psychol. Psychiatry* 42: 317–328.
Rutter M (1966) Behavioural and cognitive characteristics of a series of psychotic children. In: Wing JK (ed.) *Early Childhood Autism: Clinical, Educational, and Social Aspects*, pp. 51–81. Oxford: Pergamon.
Rutter M (1970) Autistic children: Infancy to adulthood. *Semin. Psychiatry* 2: 435–450.
Rutter M, Greenfeld D, and Lockyer L (1967) A five- to fifteen-year follow-up study of infantile psychosis. II. Social and behavioural outcome. *Br. J. Psychiatry* 113: 1183–1199.
Sacks O (1985 February 28) The twins. *N. Y. Rev.* 32: 16–20.
Sallows GO and Graupner TD (2005) Intensive behavioral treatment for children with autism: Four-year outcome and predictors. *Am J. Ment. Retard.* 110: 417–438.
Samson F, Mottron L, Jemel B, Belin P, and Ciocca V (2006) Can spectro-temporal complexity explain the autistic pattern of performance on auditory tasks? *J. Autism Dev. Disord.* 36: 65–76.
Scheerer M, Rothmann E, and Goldstein K (1945) A case of ''idiot-savant'': An experimental study of personality organization. *Psychol. Monogr.* 58: 1–63.
Scheuffgen K, Happé F, Anderson M, and Frith U (2000) High ''intelligence,'' low ''IQ''? Speed of processing and measured IQ in children with autism. *Dev. Psychopathol.* 12: 83–90.
Schover LR and Newsom CD (1976) Overselectivity, developmental level, and overtraining in autistic and normal children. *J. Abnorm. Child Psychol.* 4: 289–298.
Schreibman L (1996) Brief report: The case for social and behavioral intervention research. *J. Autism Dev. Disord.* 26: 247–250.

Schreibman L (2005) *The Science and Fiction of Autism*. Cambridge, MA: Harvard University Press.

Schreibman L and Ingersoll B (2005) Behavioral interventions to promote learning in individuals with autism. In: Volkmar F, Klin A, Paul R, and Cohen D (eds.) *Handbook of Autism and Pervasive Developmental Disorders*, pp. 882–896. Hoboken, NJ: Wiley.

Schreibman L and Lovaas OI (1973) Overselective response to social stimuli by autistic children. *J. Abnormal Ch. Psychol.* 1: 152–168.

Sears LL, Finn PR, and Steinmetz JE (1994) Abnormal classical eye-blink conditioning in autism. *J. Autism Dev. Disord.* 24: 737–751.

Sebanz N, Knoblich G, Stumpf L, and Prinz W (2005) Far from action-blind: Representation of others' actions in individuals with autism. *Cog. Neuropsychol.* 22: 433–454.

Selfe L (1977) *Nadia: A Case of Extraordinary Drawing Ability in an Autistic Child*. New York: Academic Press.

Shah A and Frith U (1983) An islet of ability in autistic children: A research note. *J. Child Psychol. Psychiatry* 24: 613–620.

Shah A and Frith U (1993) Why do autistic individuals show superior performance on the block design task? *J. Child Psychol. Psychiatry* 34: 1351–1364.

Silverberg NE and Silverberg MC (1967) Hyperlexia – Specific word recognition skills in young children. *Except. Child.* 34: 41–42.

Sinclair J (1999) Why I dislike "first person" language. http://web.syr.edu/~jisincla/person_first.htm. Accessed 13 July 2007.

Sloboda J, Hermelin B, and O'Connor N (1985) An exceptional musical memory. *Music Percept.* 3: 155–170.

Smith CJ (2003) *A Method for Testing Implicit Learning in Individuals with an Autism Spectrum Disorder.* PhD Thesis, City University of New York, New York, NY.

Smith T (1999) Outcome of early intervention for children with autism. *Clin. Psychol. Sci. Prac.* 6: 33–49.

Smith T and Lovaas OI (1998) Intensive and early behavioral intervention in autism: The UCLA Young Autism Project. *Infants Young Child.* 10: 67–78.

Smith T, Groen AD, and Wynn JW (2000/2001) Randomized trial of intensive early intervention for children with pervasive developmental disorder. *Am. J. Ment. Retard.* 105: 269–285. Erratum in *Am. J. Ment. Retard.* 105: 508. Erratum in *Am. J. Ment. Retard.* 106: 208.

Soulières I, Mottron L, Saumier D, and Larochelle S (2007) Atypical categorical perception in autism: Autonomy of discrimination? *J. Autism Dev. Dis.* 37: 481–490.

Spitz H (1995) Calendar calculating idiot savants and the smart unconscious. *New Ideas Psychol.* 13: 167–192.

Steel JG, Gorman R, and Flexman JE (1984) Neuropsychiatric testing in an autistic mathematical idiot-savant: Evidence for nonverbal abstract capacity. *J. Am. Acad. Child Psychiatry* 23: 704–707.

Szatmari P (2004) *A Mind Apart: Understanding Children With Autism and Asperger Syndrome*. New York: Guilford Press.

Szatmari P, Bartolucci G, Bremner R, Bond S, and Rich S (1989) A follow-up of high-functioning autistic children. *J. Autism Dev. Disord.* 19: 213–225.

Szatmari P, Bryson SE, Streiner DL, et al. (2000) Two year outcome of preschool children with autism or Asperger's syndrome. *Am. J. Psychiatry* 157: 1980–1987.

Tager-Flusberg H (1985a) Basic level and superordinate level categorization in autistic, mentally retarded and normal children. *J. Exp. Child Psychol.* 40: 450–469.

Tager-Flusberg H (1985b) The conceptual basis for referential word meaning in children with autism. *Child Dev.* 56: 1167–1178.

Tanaka J, Klaiman C, Koenig K, and Schultz R (2005) Plasticity of the neural mechanisms underlying face processing in children with ASD: Behavioral improvements following perceptual training on faces. International Meeting for Autism Research, Boston, MA, May 2005.

Tang J, Kennedy CH, Koppekin A, and Caruso M (2002) Functional analysis of stereotypical ear covering in a child with autism. *J. Appl. Behav. Anal.* 35: 95–98.

Taylor BA and McDonough KA (1996) Selecting teaching programs. In: Maurice C, Green G, and Luce S (eds.) *Behavioral Intervention for Young Children with Autism: A Manual for Parents and Professionals*, pp. 63–177. Austin, TX: Pro-Ed.

Thioux M, Stark DE, Klaiman C, and Schultz RT (2006) The day of the week when you were born in 700 ms: Calendar computation in an autistic savant. *J. Exp. Psychol. Hum. Percept. Perform.* 32: 1155–1168.

Toichi M, Kamio Y, Okada T, et al. (2002) A lack of self-consciousness in autism. *Am. J. Psychiatry* 159: 1422–1424.

Tomasello M (2001) *The Cultural Origins of Human Cognition*. Cambridge, MA: Harvard University Press.

Tomasello M, Kruger AC, and Ratner HH (1993) Cultural Learning. *Behav. Brain Sci.* 16: 495–552.

Tomasello M, Carpenter M, Call J, Behne T, and Moll H (2005) Understanding and sharing intentions: The origins of cultural cognition. *Behav. Brain Sci.* 28: 675–691.

Treffert DA (1988) The idiot savant: A review of the syndrome. *Am. J. Psychiatry* 145: 563–572.

Treffert DA (2000) The savant syndrome in autism. In: Accardo PJ, Magnusen C, and Capute AJ. (eds.) *Autism: Clinical and Research Issues*, pp. 193–214. Baltimore: York Press.

Turkeltaub PE, Flowers DL, Verbalis A, et al. (2004) The neural basis of hyperlexic reading: An fMRI case study. *Neuron* 41: 11–25.

Ungerer JA and Sigman M (1987) Categorization skills and receptive language development in autistic children. *J. Autism Dev. Disord.* 17: 3–16.

Volkmar FR and Klin A (2000) Diagnostic issues in Asperger syndrome. In: Klin A, Volkmar FR, and Sparrow SS (eds.) *Asperger Syndrome*, pp. 25–71. New York: Guilford.

Volkmar FR and Klin A (2005) Issues in the classification of autism and related conditions. In: Volkmar FR, Paul R, Klin A, and Cohen D (eds.) *Handbook of Autism and Pervasive Developmental Disorders*, pp. 5–41. Hoboken, NJ: Wiley.

Volkmar FR, Lord C, Bailey A, Schultz RT, and Klin A (2004) Autism and pervasive developmental disorders. *J. Child Psychol. Psychiatry* 45: 135–170.

Williams DL, Goldstein G, and Minshew NJ (2006) Neuropsychologic functioning in children with autism: Further evidence for disordered complex information-processing. *Child Neuropsychol.* 12: 279–298.

Young RL and Nettlebeck T (1995) The abilities of a musical savant and his family. *J. Autism Dev. Disord.* 25: 231–248.

# 2.40 Individual Differences in Episodic Memory

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## 2.40.1 Introduction

> Wide individual differences in learning and memory abilities have long been noted, and have been addressed in psychometric research. Unfortunately, there has been little interplay between experimental and psychometric approaches to these areas, with the result that little can be said about the relations between processes studied in experimental investigations and the dimensions of individual differences isolated in psychometric research. (Carroll, 1993: 248)

> It is shortsighted to argue for one science to discover the general laws of mind or behavior and for a separate enterprise concerned with individual minds. (Cronbach, 1957: 673)

This chapter will selectively review the vast empirical terrain regarding normal individual differences in adult human memory for newly learned information. In so doing, we will consider research conducted within both the experimental and psychometric traditions (with the latter often referred to as 'correlational,' 'differential,' and 'individual'). These two research traditions have each yielded a wealth of data and theory about varieties of memory phenomena and their structural or taxonomic relations to one another (e.g., French, 1951; Atkinson and Shiffrin, 1968; Tulving, 1985; Sherry and Schacter, 1987; Carroll, 1993; Engle et al., 1999b; Baddeley, 2000), but the work in one domain has had regrettably little impact on the other. Indeed, one could argue the same for virtually all psychological phenomena that are studied by experiment on one hand and correlations among mental tests on the other (Cronbach, 1957).

Episodic memory, in particular, provides an interesting history regarding the hesitant dance between experimental and psychometric approaches to psychological science. For while the empirical study of human memory began by deriving nomothetic principles from the intense examination of one man (Ebbinghaus, 1885), the pursuit of individual differences in memory, and their relation to the broader intellect, was very close behind. Indeed, Jacobs's (1885) review of Ebbinghaus's book, and his subsequent (1886) call to create a Society for Experimental Psychology, predicted that the new science of memory would provide psychologists a window into people's mental abilities and a means by which to rank them:

> May we hope to see the day when school registers will record that such and such a lad possesses 36 British Association units of memory-power...? If this be visionary, may we at least hope for much of interest and practical utility in the comparison of the varying powers of different minds which can now be laid down to scale. (Jacobs, 1885: 456)
>
> There is, I submit, a certain number of syllables up to which each person can repeat a nonsense word like *borg-nap-fil-trip* after only once hearing; and it is probable, though we cannot know for certain, that this number varies with different persons, giving a sort of test of their linguistic capacity. (Jacobs, 1886: 53)

Jacobs was right: People differ in their immediate memory capacity, and these differences are associated with other linguistic, and nonlinguistic, abilities. We know this, in part, because Jacobs (1887) invented the venerable memory span task for one of the first systematic individual-differences studies of memory. Schoolchildren heard and attempted to repeat lists of unrelated syllables, letters, or digits, and the largest set that each could perfectly reproduce was termed his or her span of prehension. Jacobs found this span to increase with chronological age and with higher school marks. The theoretical and practical links between memory span and intelligence, thus forged, persist to this day (albeit with controversy; Ackerman et al., 2005; Kane et al., 2005; Oberauer et al., 2005).

Ebbinghaus's and Jacobs's work represents the roots of parallel traditions of modern memory research. In caricature, the experimental approach discovers and explains lawful regularities of memory by analyzing the learning and remembering yielded by various laboratory conditions with univariate, ANOVA-based analyses; the differential approach discovers and explains lawful variation in memory by analyzing the learning and remembering yielded by a variety of valid and reliable tests with multivariate, regression-based analyses. The reality, of course, is more nuanced, with some cross-fertilization of theory, method, and analysis between experimental and psychometric traditions. We view such integration as critically important to the health of our discipline, and we argue that it is nowhere more prominent or promising today than in the study of working memory (WM). Thus, after discussing further the persisting tension between differential and experimental psychology in general, and then reviewing the largely atheoretical psychometric literature on individual differences in broad aspects of episodic memory, we will focus on theoretically motivated research that combines experimental and correlational methods to examine variation in WM (for a variety of theoretical views on WM variation, see Conway et al., 2007).

## 2.40.2 Psychology's 'Two Disciplines'

About once every generation, a prominent psychologist has called for a unification of experimental and psychometric psychology. As early as 1924, Terman argued against the looming notion that psychometric tests served mainly diagnostic and technological purposes, whereas experiments (and their 'tasks') sought discovery and theoretical advance. While acknowledging that mental tests often serve practical interests, Terman (1924) also highlighted the 'testing' research by theorists such as Spearman, Cattell, Hall, and Thorndike that firmly aimed to illuminate the basic nature of mental phenomena. He concluded that:

> One would probably be safe in predicting that the next decade will see a large interaction between the psychology of mental tests and the experimental psychology of thinking. On the one hand, the opening up of problems of individual differences by means of tests will inevitably lead to the more intensive study of such differences by the usual laboratory methods; and, on the other hand, the success attained by tests in the diagnosis of abilities for useful purposes is likely in turn to have a considerable effect upon the technique of experimental psychology. (Terman, 1924: 113)

### 2.40.2.1 Separate but Equal

If Terman (1924) had been right, of course, Cronbach's (1957) classic lament on the rift between "the two disciplines of scientific psychology," over a quarter century later, would have been unnecessary. Cronbach colorfully characterized the distinction between experimental and correlational psychology in their reactions to individual differences. For experimental psychology, they represent 'error variance,' an intolerable nuisance to be minimized. For correlational psychology, in contrast, individual differences represent the results of important physiological, environmental, and developmental causes: "The correlational psychologist is in love with just those variables the experimenter left home to forget" (p. 674). Cronbach noted some examples of methodological integration with optimism, such as in experimental approaches to development, and, like Terman, he hoped that experimental and psychometric psychology would eventually capitalize on each other's strengths.

What can (and should) these disciplines offer one another? Cronbach (1957) suggested that, on one hand, experimental evidence can provide a source of construct validation for the psychometrician. If, for example, individual differences in some test scores are thought to reflect a particular construct, such as memory confidence, then scores should vary with experimental manipulations of confidence. On the other hand, the experimentalist would benefit from the psychometrician's multivariate methods, which yield optimally reliable and valid measures of hypothetical constructs. That is, experimental tests of theories about multifaceted phenomena need not focus on only a single, impure dependent variable, nor do ostensible classes of independent variables need to be categorized via intuition or tradition. Instead, correlational techniques such as factor analysis may provide simplification and organization of complex patterns of treatments and outcomes. Thus, for Cronbach, the experimentalists' study of variation among treatments and the psychometrician's study of variation among individuals should be combined in the pursuit of individual-by-treatment interactions. Such interactions are exactly what Melton later urged memory researchers to pursue:

> . . .the sooner our experiments on human memory and human learning consider the differences between individuals in our experimental analyses of component processes in memory and learning, the sooner we will have theories and experiments that have some substantial probability of reflecting the fundamental characteristics of those processes. (Melton, 1967: 250)

### 2.40.2.2 A Crucible for Theory Testing?

Unfortunately, no federation of psychological disciplines had yet been established by 1975 when Underwood found it necessary to convince experimental psychologists that an individual-differences approach could be useful to theory testing. A verbal-learning experimentalist, Underwood advocated that correlational studies could provide a useful 'go ahead' signal to new theories. His argument was that most nomothetic theories of mental process make idiographic predictions, and that these predictions should be tested early on to determine whether a theory warrants pursuit. That is, if individual-differences predictions fail to materialize, such falsification indicates that the theory requires revision. In Underwood's words, individual-differences research provides a 'crucible' in which to test general theory.

Cronbach's (1957) and Underwood's (1975) *American Psychologist* articles are both psychology classics, with over 1000 scientific citations combined. One might expect, then, that psychologists have finally gotten the message and are regularly testing their theories with individual-by-treatment interactions. On the contrary, this millennium saw yet another call for uniting experimental and psychometric disciplines, but here to bridge psychology and biology. Kosslyn et al. (2002) described studies in which experimental and correlational approaches to theoretical questions regarding mental imagery, avoidance, mood, stress, and immune function had yielded compelling theory confirmation, ruled out alternative explanations, clarified conflicting results, or illuminated biological mechanisms that had been obscured by averaging over subjects. They concluded that neither approach, by itself, would have accomplished these ends:

> Neither group nor individual differences research alone is sufficient; researchers need to combine the two. Indeed, by combining the two, one may discover that the group results reflect the combination of several strategies, each of which draws on a different (or partially different) system. Thus, the group and individual differences findings mutually inform each other, with the synergy between them illuminating the complex relations between psychology and biology. (Kosslyn et al., 2002: 348)

### 2.40.2.3 A Crucible for Theory Testing!

As an example of this combined experimental-psychometric approach to the study of memory, Underwood put his money where his mouth was in a large correlational study of episodic memory tasks. Underwood et al. (1978) tested whether the attributes of episodic memory that had been proposed to account for experimental results (Underwood, 1969, 1982) also influenced individual differences in remembering. They administered, to 200 subjects, 24 different word-memory tests (e.g., free recall, paired-associate learning, serial recall, memory span, recognition), which measured six ostensible memory attributes: imagery, implicit associative, acoustic, temporal, affective, and frequency.

To test whether episodic memory could, in fact, be carved at its attributes, Underwood et al. (1978) factor analyzed the 24 memory tests. Factor analysis is a statistical procedure that reduces a large number of manifest test variables into a smaller number of unobserved, latent factors by examining the correlations between tests. Simply put, a factor represents the common variance among a group of measures. A test's factor loading indicates how much of its variance is captured by the factor, with higher loadings indicating a stronger association. Factors are easiest to interpret when tests are dominated by a single factor, that is, when they have high loadings on one factor and small loadings on others. Imagine, for example, that a collection of memory-span and immediate free-recall and recognition tests all load onto one factor, and a collection of span, free-recall, and recognition tasks requiring delayed memory all load onto another, with each task having near-zero loadings on the other factor. Such factor loadings would provide psychometric validation for the theoretical distinction between short- and long-term memory. In a sense, then, factors are theories about the tasks they represent (Carroll, 1993).

Five interpretable factors emerged from the Underwood et al. (1978) tasks, but they were disappointing for contemporary theory. First, the factors corresponded to the task categories rather than to attributes: factor 1 reflected primarily the paired-associate tasks, factor 2 the free-recall tasks, factor 3 the memory-span tasks, factor 4 the recognition and frequency-estimation tasks, and factor 5 the verbal discrimination tasks. None of the attributes of interest appreciably affected the factor loadings of tasks, despite some having significant and substantial experimental effects (e.g., concrete words were better remembered than abstract words). Second, the recognition and verbal discrimination tasks loaded onto separate factors. This was surprising because verbal discrimination and recognition memory were both explained by frequency theory, according to which the cue used to discriminate between two words is the perceived difference in linguistic frequency. Verbal discrimination and recognition tests, therefore, should have loaded on the same factor, but they did not. As Underwood et al. put it,

> Perhaps never before has a theory that evolved from experimental work been so savagely attacked by a correlational approach. (Underwood et al., 1978: 416)

Of course, this is just as Underwood (1975) would have had it.

(For Underwood et al. (1978), these findings did not falsify the claim that memory attributes are distinguishable and important to memory theory. Subtleties in their data suggested that subjects could strategically attend to particular attributes depending on their prior experiences and task demands, and so memory attributes were important phenomena to continue considering.)

Before considering more recent research that has attempted to meet the appeals of Terman, Cronbach, Underwood, and Kosslyn, by uniting the correlational and experimental approaches to memory research, we first highlight the key findings and conclusions drawn from the psychometric study of healthy young adults. The rest of this volume will amply review the fruits of experimental approaches, and individual chapters by Naveh-Benjamin (*See* Chapter 2.41), Ornstein (*See* Chapter 2.37), and Rovee-Collier (*See* Chapter 2.36) will consider memory's lifespan development.

## 2.40.3 The Psychometric Approach to Memory

Memory tasks have appeared within standardized intelligence test batteries since their inception (e.g., Cattell and Galton, 1890; Binet and Simon, 1905; Wechsler, 1997; Roid, 2003). Until recently, however, particular memory processes have only sporadically been linked theoretically to aspects of 'intelligent' behavior, such as complex learning, comprehension, or reasoning (e.g., Blankenship, 1938; Bachelder and Denny, 1977a,b; Dempster, 1981, 1991). In fact, most of the twentieth century saw research on memory variation take a distinctly bottom-up, atheoretical approach, by 'throwing into the hopper' a number of different mental tests, including some involving memory, and examining the resulting factor structure. We discuss these studies before reviewing more theoretical, top-down approaches to individual differences in memory.

### 2.40.3.1 The Structure of Memory, from the Bottom Up

Prototypical studies tested between 30 and 200 subjects on a battery of popular, standardized tests assessing a range of cognitive abilities, from pitch perception, to motor speed, to mental rotation, to mechanical knowledge, to reading comprehension, to abstract reasoning. Fewer than five memory tests usually appeared in these batteries, selected more for their availability than for their utility in evaluating theoretical questions. Indeed, most of these studies assessed the structure of intellect, broadly defined, rather than examining the structure or processes of memory, proper. The memory tests that were used most often were memory span, paired-associates, recognition, and free recall. We described memory span earlier, and subsequent studies did not veer far from Jacobs's (1887) original methods. Paired-associate tests usually tested subjects on novel stimulus pairings, such as between unrelated words, words and digits, or first and last names, with the test presented almost immediately after learning. Recognition and free-recall tasks varied widely in their methodological details, but most presented verbal material and imposed only brief study–test delays.

#### *2.40.3.1.1 Factor-analytic findings*

French (1951) and Carroll (1993) have reported comprehensive reviews of factor-analytic studies of intelligence (the former qualitative, the latter quantitative). Because Carroll's analyses subsumed most of French's, our discussion relies heavily on Carroll (1993).

##### *2.40.3.1.1(i) First-stratum memory factors*

'First-stratum' memory factors refer to those that represent associations among individual psychometric tests assessing relatively narrow cognitive abilities. Carroll's (1993) review, which included reanalyses (via exploratory factor analysis) of 117 datasets on intelligence, found strong evidence for four distinct memory factors: memory span, associative memory, free-recall memory, and meaningful memory (other potential factors, such as visual memory, were identified more provisionally).

Seventy datasets provided strong evidence that memory-span tests comprised a separate factor from other memory tests, usually as a single factor regardless of stimulus type or modality. At the same time, some studies indicated modest separation between verbal and nonverbal tests, and most did not include enough tests to draw strong conclusions about the unity of memory span. Limited evidence also suggested that the use of supraspan lists and the induction of interference by interpolation of lists yielded a factor separate from the standard span test (e.g., Hunt et al., 1973, 1975). We will discuss related findings in our subsequent treatment of theoretically motivated psychometric research.

Although their respective datasets were fewer (51 and 12, respectively), Carroll also provided evidence that associative-memory and free-recall factors were separate from memory span. As in French's (1951) earlier review, paired-associate tests were the best indicators of the associative-memory factor, but it also loaded (more weakly) on recognition tests and serial-recall tests. Associative processes may thus be involved in learning for, and cuing in, both recognition and serial recall. Stimulus type did not appear to affect the correlations among paired-associate tests, as was true for memory span. Free-recall tests were also frequently discriminable from both memory span and associative memory, thus forming a separate factor of their own, and this was especially so when the tests presented supraspan lists. For example, in Games (1962), letter-span tests with list lengths of ten loaded with other free-recall tests rather than with traditional span tests.

##### *2.40.3.1.1(ii) Higher-stratum memory factors*

Individual differences in memory span, paired-associate recall, and free recall are psychometrically separable. Should we therefore propose that they measure discrete mental abilities and cognitive processes? The answer is yes and no, depending on the stratum we consider within memory's hierarchical structure. Carroll (1993) showed that these factors emerge reliably at the first stratum, reflecting the correlations among individual memory tests. But their factorial separation does not imply stochastic independence. This is because memory tests of all types tend to correlate positively, and studies that include enough tests of each first-stratum memory factor find that their factors correlate, too. Indeed, Carroll's analyses yielded a higher-stratum 'general memory' factor, that is, a single memory factor at a higher level of the hierarchy that subsumed all the memory factors at the lower level. So, while it is true that people's performance on a memory-span test correlates more strongly with other span tests than it does with paired-associate tests or free-recall tests, these different memory tests all correlate more strongly with one another than they do with other kinds of mental tests. Individual differences thus suggest a general ability to remember recently experienced events or newly learned information.

Of importance, the finding of a general memory factor comprising memory span, associative/recognition memory, and free recall replicates across multiple investigators, using a variety of statistical techniques, working under different hierarchical theories of intelligence. For example, the Horn-Cattell theory of general fluid and crystallized intelligence (Gf-Gc theory; Horn and Cattell, 1966), which is based on a wealth of lifespan development data, proposes a 'short-term acquisition and retrieval' (SAR) factor at a second stratum that bears striking resemblance to Carroll's (1993) general memory factor. As described by Horn (1988), SAR factors typically comprise memory-span, associative-memory, and free-recall memory tests that impose brief delays between study and test. Horn thus describes SAR as reflecting attention to, and maintenance of, information for use in other cognitive processes (by analogy to Baddeley and Hitch's (1974) notion of WM).

The reliable presence of a higher-order memory factor that is general to many varieties of episodic memory tests indicates that, despite differences that are indicated by separate first-order factors, some abilities or processes are common to episodic memory tasks, and they vary reliably among adults. As such, any compelling theory of performance in an episodic-memory task must explain both the processes that are unique to it and the processes that are shared with other episodic memory tasks (Carroll, 1993).

#### *2.40.3.1.2 Summary*

Early factor-analytic studies of intelligence tested no particular theory of memory and selected tasks more for their convenience than for representativeness or utility in testing claims about memory process or function. Despite this important limitation, we can draw a few broad conclusions about individual differences in memory. First, paired-associate and recognition-memory tests measure some common processes or abilities that cause them to correlate strongly with one another, and more strongly with one another than with memory-span and free-recall tests, which are also discriminable from each another. Second, despite their differences, these memory tests all correlate more strongly with one another than they do with other, nonmemory tests, indicating some common processes or abilities across tests that assess memory for information learned some seconds or minutes ago.

### 2.40.3.2 The Structure of Memory, from the Top Down

The last decade has witnessed a surge in the application of individual-differences analyses to theoretical questions about memory, and we are especially interested in research on the ostensible distinction between short-term memory (STM) and WM, in part because a growing and controversial literature suggests that WM, more than STM, provides clues about the nature of general intelligence (e.g., Ackerman et al., 2005; Kane et al., 2005; Oberauer, et al., 2005). Before we review this research, it is worth noting that the recent WM literature is not unique in taking a top-down psychometric approach to theory testing. Recall the Underwood et al. (1978) use of correlational data in testing frequency theory as well as some broader claims regarding memory attributes. Moreover, factor analyses of putative STM versus long-term memory (LTM) measures have provided evidence for their conceptual, if not structural, distinction (e.g., Robertson-Tchabo and Arenberg, 1976; Geiselman et al., 1982), as have analyses of tests reflecting episodic versus semantic memory (e.g., Carroll, 1993; Nyberg, 1994).

#### *2.40.3.2.1 A distinction between STM and WM*

The terms 'STM' and 'WM' are sometimes used interchangeably as generic labels for phenomena or tasks where little time intervenes between the study and test of a limited amount of information. Other times they are used to represent competing theoretical conceptions of immediate memory, with STM commonly designating a monolithic limited-capacity memory structure involved in active rehearsal of information and its transfer into LTM (e.g., Atkinson and Shiffrin, 1968), and WM referring to a joint memory and attention system that keeps information accessible in the service of ongoing and complex cognitive activities, such as comprehension or problem solving, with separate representational and rehearsal systems for different kinds of information (e.g., Baddeley, 2000). Recent psychometric research has asked the simple question: Do individual differences distinguish these hypothetical constructs?

Cantor et al. (1991) seem to have first addressed this question rigorously. They tested 49 undergraduates in three kinds of immediate serial-recall tasks with verbal or numerical stimuli. Two probe-recall tasks presented lists of nine items, with each list followed by a cue to recall either the first, second, or third three items from the list (with the latter two assessing immediate memory). Two traditional memory-span tests (or 'simple-span,' or 'STM-span' tests) presented sequences of three to nine items for immediate recall. Two complex memory-span tests (or 'WM span') presented to-be-recalled sequences of two to seven stimuli interpolated with a secondary processing task; both presented a sentence to be read aloud between memory items. The complex span tasks were thought to reflect WM, as conceived by Baddeley and Hitch (1974), because they demanded subjects to do more than simply retain information within a storage buffer via overlearned rehearsal strategies. Their requirement that subjects maintain access to stimuli in the face of a simultaneous processing demand sought to bring attentional, executive processes to bear on maintenance (see Daneman and Carpenter, 1980). Factor analyses yielded two factors, one representing the variance common to simple span and probe-recall tasks ('STM,' with factor loadings from .54 to .95), and one representing variance common to complex span ('WM,' with factor loadings of .74 and .82). It thus appeared that tasks requiring the immediate serial recall of stimuli without the imposition of secondary tasks (i.e., STM tasks) measured at least some different cognitive processes than did those with the imposition of secondary tasks (i.e., WM tasks).

Engle et al. (1999b) took a more sophisticated analytic approach to this issue. They tested 133 subjects on three simple and three complex span tasks (all with verbal or numerical stimuli), and used confirmatory factor analysis (CFA) to test a one- versus two-factor solution to the data. CFA allows researchers to impose a theoretically informed factor model on the data and statistically test whether it fits; it also allows for statistical comparison of competing models. Here, a single-factor model did not fit the data, but a two-factor model distinguishing simple (STM) from complex (WM) span did (and the two-factor model fit significantly better than the unitary model). STM and WM span factors were correlated, but not strongly enough to yield a single memory factor. Thus, with verbal materials, simple and complex span tasks measure some independent mental processes and support the view that WM is, in part, a separate cognitive system from STM. Although we cannot review the relevant findings in detail, the WM-STM distinction is reinforced by numerous reports of WM span factors correlating more strongly and broadly with factors representing complex cognitive abilities (e.g., comprehension and reasoning) than do STM span factors (e.g., Engle et al., 1999a; Conway et al., 2002; Bayliss et al., 2003).

Engle and his colleagues have argued that, even though both WM and STM tasks involve some shared processes such as storage, rehearsal, and executive-attention control, WM span's imposition of secondary tasks increases the executive-attention contribution relative to that in STM span (e.g., Engle et al., 1999a; Engle and Kane, 2004; Kane et al., 2005). These executive-attention processes help maintain access to memoranda in the face of attention shifts away from their representations and toward the execution of the secondary task; that is, WM span tasks bring executive control to bear on keeping representations accessible when they are outside conscious focus. STM span tasks, because they provide no secondary task to interfere with stimulus maintenance and rehearsal, require less executive involvement.

#### *2.40.3.2.2 A distinction between STM and WM?*

But wait – subsequent research using visuospatial materials suggests a different conclusion, namely that STM and WM may be inseparable (or, at least, less separable than verbal STM and WM). Miyake et al. (2001) tested 167 undergraduates in two STM span tasks presenting sequences of visuospatial stimuli (e.g., dots within different locations of a grid), and two WM tasks interpolating a spatial processing task (e.g., mental rotation of letters) between the spatial memoranda. CFAs indicated that a model separating STM from WM fit the data well, but the correlation between these factors was very high (.86) with a 95% confidence interval including 1.0. Fixing the correlation between these factors to 1.0, thus deriving a unitary memory factor, did not significantly hurt model fit, indicating that, in the spatial domain, STM and WM were equivalent as measured by span tasks.

Although subsequent studies have not found spatial STM and WM to be indistinguishable, they have found STM and WM to be somewhat more strongly associated in the spatial than in the verbal domain (Park et al., 2002; Kane et al., 2004). One interpretation of these findings is that, because people have fewer and less-practiced rehearsal strategies for visuospatial than for verbal sequences, even 'simple' STM tasks with spatial materials draw heavily on executive-attention processes for effective maintenance. Given our emphasis in this chapter on convergence between psychometric and experimental findings, we note that the 'executive' interpretation of spatial STM-WM correlations dovetails nicely with conclusions drawn from dual-task experimental studies, which have suggested domain-general executive and attention processes are more important to short-term retention of spatial than verbal stimuli (e.g., Klauer and Stegmaier, 1997; Awh et al., 1998).

In any case, the tidy distinction between STM and WM is rapidly becoming more complicated. First, as mentioned, spatial STM and WM tasks are highly correlated and may sometimes be indistinguishable. Second, Oberauer and colleagues have demonstrated that immediate-memory tasks need not involve secondary-processing tasks to correlate strongly with WM span tasks; for example, tasks that require the updating of mental representations of several stimuli, without the imposition of irrelevant information, are just about indistinguishable psychometrically from WM span (e.g., Süß et al., 2002; Oberauer, 2005). At the same time, Unsworth and Engle (2007) have shown that non-recency portions of immediate-free-recall lists correlate so strongly with WM span that they are also psychometrically indistinguishable from each another. If WM can be measured without dual tasks, then what really distinguishes it from STM? Third, Colom and colleagues have recently argued, based on reanalyses of old datasets and analyses of new ones, that WM and STM span, even in the verbal domain, are much more highly correlated than has been recognized, and that the shared variance between WM and STM is more important to their broad power to predict cognitive individual differences than is the variance that is unique to WM (e.g., Colom et al., 2006a,b).

It now appears that the key to understanding the WM-STM relation, as assessed by span and other tasks, is to resist the reification of tasks onto hypothetical constructs. Instead, we must consider more carefully the shared and unique mental processes that determine performance. Although Engle and colleagues have emphasized the multiply determined nature of both STM and WM span (e.g., Engle et al., 1999a; Engle and Kane, 2004; Kane et al., 2005), noting that storage, rehearsal, and executive processes contribute to both tasks, many researchers assume their view to be that 'STM' tasks simply measure storage and rehearsal and 'WM' tasks measure exclusively executive control (e.g., Ackerman et al., 2005; Colom et al., 2006a).

Fortunately, Unsworth and Engle (2006, 2007) have clarified the mappings of these tasks to their underlying constructs. In short, WM span tasks, STM span tasks with long (more than four item) lists, and nonrecency portions of free-recall lists all measure just about the same thing ('WM'), and all seem to account for similar variance in higher-order cognitive abilities. Why should this be? Unsworth and Engle argue that, in all of these cases, subjects must recover some or all of the target information from 'secondary,' inactive memory in the face of competition from other memory representations. To do so, subjects use cues to guide memory search and delimit a search set that discriminates target from competing information. Higher WM subjects appear to generate and use better cues, or to use the same cues more effectively, than do lower WM subjects, and this accounts for their better performance on these varied memory tests.

#### *2.40.3.2.3 Summary*

The individual-differences literature on STM and WM yields an irony. Tasks such as STM and WM span are assumed to measure immediate-memory and attention-related processes that are quite different from those involved in LTM encoding and retrieval. However, current evidence suggests that search and retrieval from inactive secondary memory (or LTM), rather than maintenance within active primary memory, drives individual differences in memory-span and span–ability correlations. These conclusions seem quite consistent with those from experimental studies suggesting that, aside from a very limited number of highly active and accessible representations we might call primary memory, retention and recall over both the short and long term is driven primarily from the cue-driven search and retrieval of inactive memory (e.g., Wickelgren et al., 1980; Wixted and Rohrer, 1994; McElree, 1998; Cowan, 2001; Nairne, 2002; Davelaar et al., 2005). The clear lesson is that we should not assume that the processes engaged by tasks follow from the labels, such as 'STM span,' that we have traditionally affixed to them.

## 2.40.4 Individual-by-Treatment Interactions in Memory

In both applied and general scientific work, psychology requires combined, not parallel, labors from our two historic disciplines.... In the search for

> interactions we will invent new treatment dimensions and discover new dimensions of the organism. We will come to realize that organism and treatment are an inseparable pair and that no psychologist can dismiss one or the other as error variance. (Cronbach, 1957: 683)

Cronbach (1957) called for a united psychology to bring the strengths of experimental and psychometric methods to bear on theoretical and practical problems of human behavior, in particular by seeking interactions among individuals and experimental treatments. We believe that the literature on individual differences in WM is rich with examples of this approach, and so we review briefly two categories of such studies. In the first, experimental manipulations of the WM span task, itself, are tested for their effect on correlations between WM span and some criterion variables, such as language comprehension or reasoning. In this way, researchers isolate some of the cognitive processes that are most important and least important to the predictive power of WM span (e.g., retrieval of information in the face of proactive interference, and engaging in particular mnemonic strategies, respectively). In the second category, WM-related individual differences are assessed within other, nonspan tasks that feature various experimental manipulations designed to be more or less vulnerable to WM variation. This correlational technique may often yield significant advances in general theory about cognitive tasks and task domains.

### 2.40.4.1 Individual-by-Treatment Interactions within WM Span Tasks

WM span tasks are complex. They require timesharing between two unrelated tasks, such as memorizing letters and solving equations, they afford numerous strategies for managing the dual-task requirement and for encoding memoranda, and they present processing material that may be more or less demanding for subjects with different skills. So which of these variables, if any, are important to the correlations between WM span and various complex cognitive abilities?

Individual differences in skill on the processing task (Conway and Engle, 1996), or in strategy use (Dunlosky and Kane, in press), are not. Let us consider strategy use in more detail. If differential strategy use (or efficiency) were largely responsible for WM span correlating with, say, reading comprehension scores, then experimentally manipulating strategy use should alter the span–comprehension association. What actually happens? When subjects are allowed to pace themselves through WM span tasks, thus allowing more time to study the items and employ complex mnemonics, mean scores go up. This experimental effect is not surprising. What is more important is the individual-by-treatment interaction: the span–comprehension correlations either remain unchanged, or get weaker, as a result of this experimental manipulation (Engle et al., 1992; Friedman and Miyake, 2004).

The fact that, if anything, span correlations get weaker when we allow subjects more freedom in their approaches to the task suggests that normal individual differences in these approaches or strategies are not responsible for the strong correlations normally observed. In fact, strategic variation appears to contribute noise to span correlations rather than causing them. If strategic variation were actually causal, then allowing strategies to vary more freely should increase the correlations, not decrease them. Indeed, in studies that teach subjects to use one particular memory strategy within WM span, the correlations get stronger compared to those from uninstructed subjects (Turley-Ames and Whitfield, 2003). By forcing all subjects to use the same strategy, nuisance variation in strategy selection is reduced, and the true (stronger) span–ability association is revealed.

What do individual-by-treatment interactions tell us about what is important to WM span variation? They tell us that the buildup of proactive interference (PI) is important. Like most immediate-memory tasks, WM span tasks present many different lists of similar items within a single test. As experimental studies of memory have long indicated, this is a recipe for PI and rapid forgetting (e.g., Underwood, 1957; Keppel and Underwood, 1962). We might expect, then, that experimental manipulations of PI should affect mean span scores, driving them up or down. Like the effect of strategy use on mean span scores discussed earlier, this would not be surprising. The really interesting question, again, is about the individual-by-treatment interaction: Do experimental manipulations of PI affect individual differences in WM span and its correlation with other tasks?

Indeed they do. May et al. (1999) presented WM span trials in one of two orders to younger and older adults. In ascending orders, smaller memory sets were presented before larger sets. Thus, larger sets, which by convention contribute more to span scores than do smaller sets, were encountered only after PI had built up from prior trials. In descending orders, the high-impact larger sets were presented first and, therefore, before PI had much effect. May et al. found not only that descending administrations yielded higher mean scores than did ascending, but also that age differences in WM span, which are usually robust, arose only in the ascending administration. By minimizing the effect of PI on subjects' scores via descending administration, the ubiquitous age-by-span correlation was eliminated. Lustig et al. (2001) and Bunting (2006) have further demonstrated that experimentally reducing PI during span tasks dramatically reduces their correlations with comprehension and reasoning tests. Likewise, Gray et al. (2003) used neuroimaging techniques to show not only that increasing the contribution of interference to WM tasks increases their correlation to reasoning tests, but also that this correlation is almost completely accounted for by individual differences in the recruitment of brain areas that are important to executive control. The fact that reducing interference reduces WM span correlations, and increasing interference increases span correlations, suggests that PI and individual differences in the ability to resist it are important causal variables in the relation between WM span and higher-order cognition. Only investigations of individual-by-treatment interactions could have led to such conclusions.

### 2.40.4.2 Individual-by-Treatment Interactions in the Effects of WM on Other Tasks

As we have seen, one effective method to investigate the strong empirical associations between WM span and various cognitive abilities is to manipulate variables within span tasks and then measure their effects on span–ability correlations. Another common strategy in this literature is to test for WM-related individual differences in the performance of other tasks under varying experimental conditions. In the domain of complex cognitive abilities, for example, WM span and language comprehension correlate significantly under some experimental conditions, but not others, suggesting theoretical distinctions between more resource-demanding and more automatic referential and parsing processes (e.g., Just and Carpenter, 1992; Caplan et al., 2007). Regarding somewhat more simple cognitive processes, such as selective attention and visual search, WM span also correlates strongly and selectively with performance in only some task contexts, and these differential correlations have fueled novel theoretical proposals for how such attention tasks are performed (e.g., Kane and Engle, 2003; Kane et al., 2006; Heitz and Engle, 2007).

As we emphasized the importance of PI to span–ability correlations earlier, let us consider here what WM-by-treatment interactions tell us about PI and the executive control of memory processes, quite generally. Nomothetic theory derived from experiments has suggested that executive selection and inhibitory processes play significant roles in producing and combating PI (e.g., Postman et al., 1968; Anderson, 2003). Because WM variation has been thought to reflect, in part, variation in such executive-control processes, Kane and Engle (2000) investigated the relation between WM span and PI buildup in a variant of the Brown-Peterson task. Subjects who had been previously identified as having high WM span scores (i.e., from the top quartile of a large university distribution) or low WM scores (i.e., from the bottom quartile) studied and recalled three consecutive lists of ten words drawn from one semantic category (animals, occupations, or world nations). Immediately following each list, subjects engaged in a rehearsal-prevention task for 16 s before recalling the list. High- and low-WM subjects did not differ in recall of the first list but, as expected, WM span predicted PI susceptibility, with low-WM subjects showing greater PI on lists 2 and 3 than did high-WM subjects. Although this finding represents an individual-by-treatment interaction, with WM span predicting recall across late but not early lists, more generally important findings came from a higher-order interaction.

While Kane and Engle (2000) tested for WM-related individual differences in PI susceptibility, they also manipulated subjects' capacity for executive control by dividing their attention. During either the encoding or retrieval of each list, subjects continuously tapped a pseudorandom finger sequence under time pressure. The logic here was similar to that in neuropsychological studies of brain injury: task components that normally elicited executive control would suffer under dual-task conditions, as those executive processes were thwarted by the tapping task. Two relevant results warrant mention. First, divided attention increased the PI effects for high-WM subjects and had no effect on their list 1 recall, suggesting that high spans engaged attention-control processes only to meet the increased encoding and retrieval demands of PI-vulnerable lists. In fact, high WM performance in the dual-task conditions matched low WM performance under single-task conditions, and so dividing attention turned high-WM subjects into functional low-WM subjects. Second, and in contrast, divided attention hurt low-WM subjects' list 1 recall while having no subsequent effect on their PI susceptibility. This suggests that low-WM subjects exhausted their attention-control processes to meet the basic encoding and retrieval requirements of single lists with little PI potential, leaving nothing additional to exert against the interference on subsequent lists. These findings suggest some interesting hypotheses about the nature of WM-related individual differences, but they also paint a much more complicated picture regarding the attentional demands of encoding and retrieval than is typically considered (e.g., Craik et al., 1996). We suggest that further investigation of span-by-treatment interactions would be informative to nomothetic theoretical pursuits regarding the nature of episodic memory and retrieval and their interaction with attentional processes.

## 2.40.5 Summary and Conclusions

The psychological investigation of memory, like psychological investigations of other behavioral and cognitive phenomena, has been slow to integrate the experimental and correlational approaches to theory testing. We hope to have convinced experimentally inclined cognitive researchers that they should consider the psychometric literature on individual differences in memory in forming hypotheses about memory processes and tasks. Moreover, they should consider incorporating individual differences into their own experimental tests of such hypotheses. Our plea, like Terman's, Cronbach's, Melton's, Underwood's, and Kosslyn's before us, is that students of memory whose interests span traditional areas of memory research (so well represented in this volume) will recognize the potential benefits of a united experimental–psychometric approach to important theoretical questions about memory structure and process.

## References


Ackerman PL, Beier ME, and Boyle MO (2005) Working memory and intelligence: The same or different constructs? *Psychol. Bull.* 131: 30–60.

Anderson MC (2003) Rethinking interference theory: Executive control and the mechanisms of forgetting. *J. Mem. Lang.* 49: 415–445.

Atkinson RC and Shiffrin RM (1968) Human memory: A proposed system and its control processes. In: Spence KW and Spence JT (eds.) *The Psychology of Learning and Motivation,* vol. 2, pp. 89–195. New York: Academic Press.

Awh E, Jonides J, and Reuter-Lorenz PA (1998) Rehearsal in spatial working memory. *J. Exp. Psychol. Hum. Percept. Perform.* 24: 780–790.

Baddeley AD (2000) The episodic buffer: A new component of working memory? *Trends Cogn. Sci.* 4: 417–423.

Baddeley AD and Hitch G (1974) Working memory. In: Bower GA (ed.) *The Psychology of Learning and Motivation,* vol. 8, pp. 47–89. New York: Academic Press.

Bachelder BL and Denny MR (1977a) A theory of intelligence: I. Span and the complexity of stimulus control. *Intelligence* 1: 127–150.

Bachelder BL and Denny MR (1977b) A theory of intelligence: II. The role of span in a variety of intellectual tasks. *Intelligence* 1: 237–256.

Bayliss DM, Jarrold C, Gunn DM, and Baddeley AD (2003) The complexities of complex span: Explaining individual differences in working memory in children and adults. *J. Exp. Psychol. Gen.* 132: 71–92.

Binet A and Simon T (1905) Méthodes nouvelles pour le diagnostic du niveau intellectuel des anormaux. *Annee Psychol.* 11: 191–244.

Blankenship AB (1938) Memory span: A review of the literature. *Psychol. Bull.* 35: 1–25.

Bunting MF (2006) Proactive interference and item similarity in working memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 183–196.

Cantor J, Engle RW, and Hamilton G (1991) Short-term memory, working memory, and verbal abilities: How do they relate? *Intelligence* 15: 229–246.

Caplan D, Wathers G, and DeDe G (2007) Specialized verbal working memory for language comprehension. In: Conway ARA, Jarrold C, Kane MJ, Miyake A, and Towse JN (eds.) *Variation in Working Memory*, pp. 272–302. New York: Oxford University Press.

Carroll JB (1993) *Human Cognitive Abilities: A Survey of Factor-Analytic Studies*. Cambridge: Cambridge University Press.

Cattell JM and Galton F (1890) Mental tests and measurements. *Mind* 15: 373–381.

Colom R, Rebollo I, Abad FJ, and Shih PC (2006a) Complex span tasks, simple span tasks, and cognitive abilities: A reanalysis of key studies. *Mem. Cogn.* 34: 158–171.

Colom R, Shih PC, Flores-Mendoza, and Quiroga MA (2006b) The real relationship between short-term memory and working memory. *Memory* 14: 804–813.

Conway ARA, Cowan N, Bunting MF, Therriault D, and Minkoff S (2002) A latent variable analysis of working memory capacity, short term memory capacity, processing speed, and general fluid intelligence. *Intelligence* 30: 163–183.

Conway ARA and Engle RW (1996) Individual differences in working memory capacity: More evidence for a general capacity theory. *Memory* 4: 577–590.

Conway ARA, Jarrold C, Kane MJ, Miyake A, and Towse JN (2007) *Variation in Working Memory*. New York: Oxford University Press.

Cowan N (2001) The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behav. Brain Sci.* 24: 87–185.

Craik FIM, Govoni R, Naveh-Benjamin M, and Anderson ND (1996) The effects of divided attention on encoding and retrieval processes in human memory. *J. Exp. Psychol. Gen.* 125: 159–180.

Cronbach LJ (1957) The two disciplines of scientific psychology. *Am. Psychol.* 12: 671–684.
Daneman M and Carpenter PA (1980) Individual differences in working memory and reading. *J. Verbal Learn. Verbal Behav.* 19: 450–466.
Davelaar EJ, Goshen-Gottstein Y, Ashkenazi A, Haarmann HJ, and Usher M (2005) The demise of short-term memory revisited: Empirical and computational investigations of recency effects. *Psychol. Rev.* 112: 3–42.
Dempster FN (1981) Memory span: Sources of individual and developmental differences. *Psychol. Bull.* 89: 63–100.
Dempster FN (1991) Inhibitory processes: A neglected dimension in intelligence. *Intelligence* 15: 157–173.
Dunlosky J and Kane MJ (in press) The contributions of strategy use to working memory span: A comparison of strategy assessment methods. *Q. J. Exp. Psychol.*
Ebbinghaus H (1885) *Memory: A Contribution to Experimental Psychology*. New York: Dover Publications, Inc. [Reprinted 1964.]
Engle RW, Cantor J, and Carullo JJ (1992) Individual differences in working memory and comprehension: A test of four hypotheses. *J. Exp. Psychol. Learn. Mem. Cogn.* 18: 972–992.
Engle RW and Kane MJ (2004) Executive attention, working memory capacity, and a two-factor theory of cognitive control. In: Ross B (ed.) *The Psychology of Learning and Motivation*, pp. 145–199. New York: Academic Press.
Engle RW, Kane MJ, and Tuholski SW (1999a) Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence and functions of the prefrontal cortex. In: Miyake A and Shah P (eds.) *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*, pp. 102–134. Cambridge: Cambridge University Press.
Engle RW, Tuholski SW, Laughlin JE, and Conway ARA (1999b) Working memory, short-term memory and general fluid intelligence: A latent variable approach. *J. Exp. Psychol. Gen.* 128: 309–331.
French JW (1951) *Psychometric Monographs, No. 5: The Description of Aptitude and Achievement Tests in Terms of Rotated Factors*. Chicago: University of Chicago Press.
Friedman NP and Miyake A (2004) The reading span test and its predictive power for reading comprehension ability. *J. Mem. Lang.* 51: 136–158.
Games PA (1962) A factorial analysis of verbal learning tasks. *J. Exp. Psychol.* 63: 1–11.
Geiselman RE, Woodward JA, and Beatty J (1982) Individual differences in verbal memory performance: A test of alternative information-processing models. *J. Exp. Psychol. Gen.* 111: 109–134.
Gray JR, Chabris CF, and Braver TS (2003) Neural mechanisms of general fluid intelligence. *Nat. Neurosci.* 6: 316–322.
Guilford JP (1967) *The Nature of Human Intelligence*. New York: McGraw-Hill.
Heitz RP and Engle RW (2007) Focusing the spotlight: Individual differences in visual attention control. *J. Exp. Psychol. Gen.* 136: 217–240.
Horn JL (1988) Thinking about human abilities. In: Nesselroade JR and Cattell RB (eds.) *Handbook of Multivariate Experimental Psychology,* 2nd edn., pp. 645–685. New York: Plenum.
Horn JL and Cattell RB (1966) Refinement and test of the theory of fluid and crystallized general intelligences. *J. Educ. Psychol.* 57: 253–270.
Hunt E, Frost N, and Lunneborg C (1973) Individual differences in cognition: A new approach to intelligence. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory*, pp. 87–122. New York: Academic Press.
Hunt E, Lunneborg C, and Lewis J (1975) What does it mean to be high verbal? *Cognit. Psychol.* 7: 194–227.
Jacobs J (1885) Ueber das Gedachtnis. [Review of Ebbinghaus (1885) *Memory: A Contribution to Experimental Psychology*]. *Mind* 10: 454–459.
Jacobs J (1886) The need of a society for experimental psychology. *Mind* 11: 49–54.
Jacobs J (1887) Experiments on ''prehension.'' *Mind* 12: 75–79.
Just MA and Carpenter PA (1992) A capacity theory of comprehension: Individual differences in working memory. *Psychol. Rev.* 99: 122–149.
Kane MJ and Engle RW (2000) Working-memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 336–358.
Kane MJ and Engle RW (2003) Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *J. Exp. Psychol. Gen.* 132: 47–70.
Kane MJ, Hambrick DZ, and Conway ARA (2005) Working memory capacity and fluid intelligence are strongly related constructs: Comment on Ackerman, Beier, and Boyle (2005). *Psychol. Bull.* 131: 66–71.
Kane MJ, Hambrick DZ, Tuholski SW, Wilhelm O, Payne TW, and Engle RW (2004) The generality of working memory capacity: A latent-variable approach to verbal and visuospatial memory span and reasoning. *J. Exp. Psychol. Gen.* 133: 189–217.
Kane MJ, Poole BJ, Tuholski SW, and Engle RW (2006) Working memory capacity and the top-down control of visual search: Exploring the boundaries of ''executive attention.'' *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 749–777.
Keppel G and Underwood BJ (1962) Proactive inhibition in short-term retention of single items. *J. Verbal Learn. Verbal Behav.* 1: 153–161.
Klauer KC and Stegmaier R (1997) Interference in immediate spatial memory: Shifts of spatial attention or central-executive involvement? *Q. J. Exp. Psychol.* 50A: 79–99.
Kosslyn SM, Cacciopo JT, Davidson RJ, et al. (2002) Bridging psychology and biology: The analysis of individuals in groups. *Am. Psychol.* 57: 341–341.
Lustig C, May CP, and Hasher L (2001) Working memory span and the role of proactive interference. *J. Exp. Psychol. Gen.* 130: 199–207.
May C, Hasher L, and Kane MJ (1999) The role of interference in memory span. *Mem. Cogn.* 27: 759–767.
McElree B (1998) Attended and non-attended states in working memory: Accessing categorized structures. *J. Mem. Lang.* 38: 225–252.
Melton AW (1967) Individual differences and theoretical process variables: General comments on the conference. In: Gagné RM (ed.) *Learning and Individual Differences*, pp. 238–252. Columbus, OH: Merrill.
Miyake A, Friedman NP, Rettinger DA, Shah P, and Hegarty M (2001) How are visuospatial working memory, executive functioning, and spatial abilities related? A latent-variable analysis. *J. Exp. Psychol. Gen.* 130: 621–640.
Nairne JS (2002) Remembering over the short-term: The case against the standard model. *Annu. Rev. Psychol.* 53: 53–81.
Nyberg L (1994) A structural equation modeling approach to the multiple memory systems question. *J. Exp. Psychol. Learn. Mem. Cogn.* 20: 485–491.
Oberauer K (2005) The measurement of working memory capacity. In: Wilhelm O and Engle RW (eds.) *Handbook of Understanding and Measuring Intelligence*, pp. 393–407. Thousand Oaks, CA: Sage.

Oberauer K, Schulze R, Wilhelm O, and Süß H-M (2005) Working memory and intelligence – their correlation and their relation: Comment on Ackerman, Beier, and Boyle (2005). *Psychol. Bull.* 131: 61–65.
Park DC, Lautenschlager G, Hedden T, Davidson N, Smith AD, and Smith PK (2002) Models of visuospatial and verbal memory across the adult lifespan. *Psychol. Aging* 17: 299–320.
Postman L, Stark K, and Fraser J (1968) Temporal changes in interference. *J. Verbal Learn. Verbal Behav.* 7: 672–694.
Robertson-Tchabo E and Arenberg D (1976) Age differences in cognition in healthy educated men: A factor analysis of experimental measures. *Exp. Aging Res.* 2: 75–89.
Roid GH (2003) *Standford-Binet Intelligence Scales,* 5th edn., Technical Manual.Itasca, IL: Riverside Publishing.
Sherry DF and Schacter DL (1987) The evolution of multiple memory systems. *Psychol. Rev.* 94: 439–454.
Süß H-M, Oberauer K, Wittman WW, Wilhelm O, and Schulze R (2002) Working memory capacity explains reasoning ability – and a little bit more. *Intelligence* 30: 261–288.
Terman LM (1924) The mental test as a psychological method. *Psychol. Rev.* 31: 93–117.
Tulving E (1985) How many memory systems are there? *Am. Psychol.* 40: 385–398.
Turley-Ames KJ and Whitfield MM (2003) Strategy training and working memory task performance. *J. Mem. Lang.* 49: 446–468.
Underwood BJ (1957) Interference and forgetting. *Psychol. Rev.* 64: 49–60.
Underwood BJ (1969) Attributes of memory. *Psychol. Rev.* 76: 559–573.
Underwood BJ (1975) Individual differences as a crucible in theory construction. *Am. Psychol.* 30: 128–134.
Underwood BJ (1982) *Attributes of Memory*. Chicago: Scott, Foresman.
Underwood BJ, Boruch RF, and Malmi RA (1978) Composition of episodic memory. *J. Exp. Psychol. Gen.* 107: 393–419.
Unsworth N and Engle RW (2006) Simple and complex spans and their relation to fluid abilities: Evidence from list-length effects. *J. Mem. Lang.* 54: 68–80.
Unsworth N and Engle RW (2007) The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychol. Rev.* 114: 104–132.
Wechsler D (1997) *Manual for the Wechsler Adult Intelligence Scale,* 3rd edn. San Antonio, TX: The Psychological Corporation.
Wickelgren WA, Corbett AT, and Dosher BA (1980) Priming and retrieval from short-term memory: A speed-accuracy trade-off analysis. *J. Verbal Learn. Verbal Behav.* 19: 387–404.
Wixted JT and Rohrer D (1994) Analyzing the dynamics of free recall: An integrative review of the literature. *Psychon. Bull. Rev.* 1: 89–106.

# 2.41 Aging and Memory

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This chapter is a review of studies assessing age-related changes in memory – that is, the changes that occur in different memory systems and processes from young adulthood to old age – with the intention of establishing the major empirical findings reported in the literature, the theoretical interpretations of these findings, and directions for future research. Most of the chapter is based on the comparison of performance of young people in their twenties to older adults between 65 and 85 years old. We limit the discussion to normal age-related changes, focusing on behavioral studies in which the older participants have no apparent pathological changes related to dementia or other similar conditions (*See* Chapter 3.28 for a discussion of some of the mediating brain structures of these changes). As this research field has gone through a vast expansion in the last 25 years, the review is necessarily selective, covering several representative topics studied in the literature that use different types of conceptualizations in terms of memory stores, memory systems, and memory processes.

## 2.41.1 Introduction

One of the most intriguing aspects regarding age-related changes in memory is the variability in the changes; whereas some memory abilities decline significantly in old age, others are held fairly constant throughout older adults' years. Explaining this variability in performance is a major purpose of research in the area, and although we still lack comprehensive explanations, several promising approaches have been suggested to explain components of this variability.

Many studies have addressed questions regarding changes in different types of memory established in general memory research. For example, one distinction is between declarative (explicit) and nondeclarative (implicit) memory systems (e.g., Squire, 1986). The former involves conscious intentional retrieval (e.g., trying to remember the name of the person you met last night), whereas the latter involves memories that can be inferred by subsequent behavior without any intention to be retrieved (e.g., riding a bike, or responding faster to a stimulus because you have seen it several times before). Within the domain of declarative memory, a distinction has been made between episodic memory – that related to a particular time and place in an individual's personal history (e.g., remembering whom you met last Thursday for lunch) – and semantic memory, which involves knowledge of general facts not related to a particular time and place (e.g., knowing the capital of France). Another distinction is based on memory stores; short-term memory, for example, involves the ability to retain a recently experienced event for a brief period (such as listening over the phone for a meeting time and then writing it down), whereas long-term memory involves the retention of information for an extended period of time (e.g., remembering the names of the people you met last night for dinner). A further distinction is between retrospective memory – memory for a past event – and prospective memory – memory to perform a future action (such as remembering to show up for a dental appointment). Finally, viewing memory in terms of processing phases allows for the assessment of age-related differences in learning (encoding) the information, in maintaining it during the retention interval, and in accessing (retrieving) it when necessary.

As mentioned above, research shows differential patterns of age-related changes in tasks involving these different memory types. For example, whereas semantic memory seems to be maintained relatively well into old age, episodic memory shows an appreciable decline (**Figure 1(f)**). In addition, in contrast to explicit (declarative) episodic memory, implicit memory, as one type of nondeclarative memory, shows very few changes in old age.

We begin by describing age-related patterns in different types of memory based on empirical findings and then discuss theoretical frameworks that have been suggested to explain these patterns. We end with a discussion of some further issues, including the uniqueness of memory changes within the larger realm of general cognitive changes, tasks, and circumstances in which older adults seem to show adequate memory performance, and limitations on conclusions based mostly on laboratory research.

## 2.41.2 Empirical Findings

In order to establish reliable conclusions based on numerous studies, we have resorted, wherever possible, to meta-analytical studies of age-related differences in various memory domains. Such studies involve quantitative summaries of a large number of studies investigating specific questions and, hence, help us to draw conclusions based on replicable results. After establishing the patterns in a given domain based on each meta-analysis, we describe a few illustrative studies to provide the reader with characteristic methods and representative results for each domain. Among other issues, we discuss age-related changes in short and long-term memory, explicit (semantic and episodic) and implicit memory, and prospective memory. We also assess age-related changes in autobiographical and false memory and in encoding and retrieval processes. Most of the research is based on experimental studies, although some studies use multivariate correlational approaches.

It should be noted that most of the meta-analytical studies representing the type of studies conducted on memory and aging are based on cross-sectional designs, in which different age groups are tested at a given point in time. This method usually shows larger age-related differences than are obtained in the rather less frequently used longitudinal studies, in which groups of people are followed over time (e.g., Rönnlund et al., 2005). This point is further discussed at the end of this chapter.

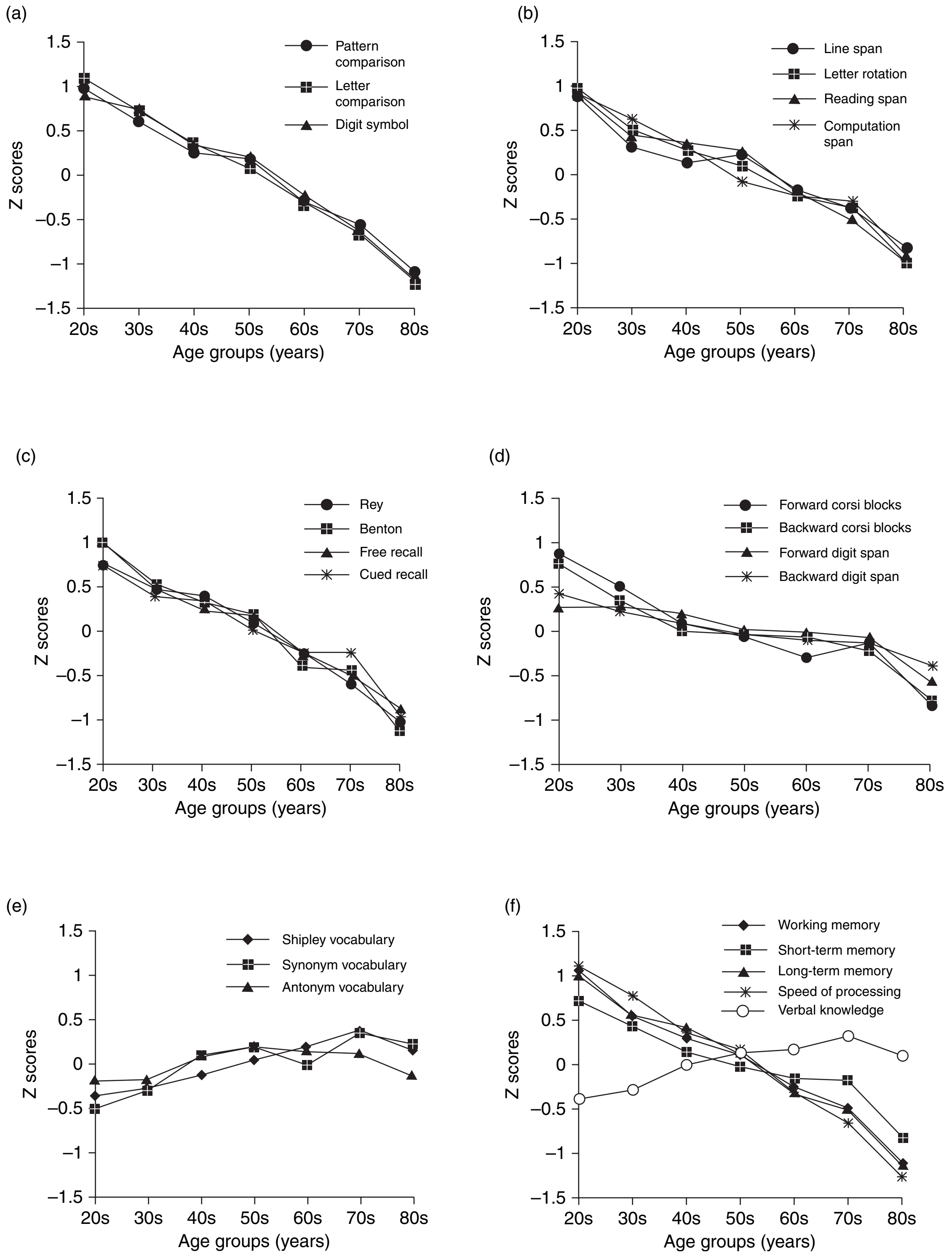


**Figure 1** Life span performance measures. (a) Speed of processing. (b) Working memory. (c) Long-term memory. (d) Short-term memory. (e) Knowledge-based verbal ability. (f) A composite view. From Park DC, Lautenschlager G, Hedden T, Davidson NS, Smith AD, and Smith PK (2002) Models of visuospatial and verbal memory across the adult life span. *Psychol. Aging* 17: 299–320. Copyright 2002 by the American Psychological Association.

### 2.41.2.1 Implicit/Indirect Memory Versus Explicit/Direct Memory

One area of memory research that received substantial attention in the 1980s and 1990s is related to the distinction between tasks in which participants are aware of the fact that their memory is being probed (explicit/direct) and those in which they are unaware of performing a memory task (implicit/indirect/procedural). Interestingly, most of the research in this area indicates different patterns of age-related changes in these two classes of memory tasks. A meta-analysis carried out by Light and La Voie (1993), based on 33 experiments, concluded that there are small age-related declines on implicit memory measures (d = −0.18, where d is the mean effect size in terms of unit standard deviations over all the studies included). However, these are much smaller than the decline shown for explicit measures such as recognition or recall, in which d ranges from −0.5 to −1.5, as found in other meta-analytical studies reviewed here (see **Figure 1(c)**).

One example of such a pattern was reported by Light and Singh (1987). In their study, older and younger adults viewed lists of words and rated each word by its pleasantness. Later, subjects were provided with the first three letters of various words, some of which had been presented earlier. Half of the participants (the implicit group) were told simply to complete each stem with the first word that came to mind, whereas the others (the explicit group) were asked to try to fill in each stem with a word they had seen earlier. Finally, all subjects completed a recognition test, in which they chose studied words from a list of both targets and distractors. The results indicated that, whereas cued recall scores and recognition scores were impaired in old age, the priming effect (i.e., providing a previously rated word following implicit instructions) did not differ significantly between age groups. Similar results were obtained by Light and Albertson (1989), who used lists of semantically categorized words with explicit cued recall and implicit exemplar generation tasks (see **Figure 2**).

Differential age-related decline in implicit versus explicit memory measures has been further supported by a longitudinal design employed by Fleischman et al. (2004). Results of several implicit and explicit tests administered once a year for 4 consecutive years showed that explicit memory declined significantly over the four assessment periods, and this decline was largest in participants who were the oldest. Implicit memory, however, was unrelated to age at baseline and did not decline over the 4-year period.

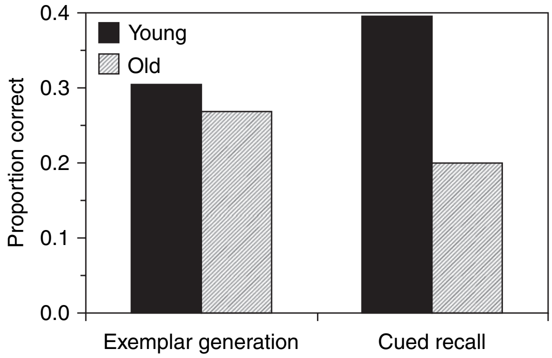


**Figure 2** Performance of older and younger adults on an implicit exemplar generation task and an explicit cued recall task. From Light LL and Albertson SA (1989) Direct and indirect tests of memory for category exemplars in young and older adults. *Psychol. Aging* 4: 487–492. Copyright 1989 by the American Psychological Association.

Altogether, older adults are impaired more on explicit than on implicit memory measures. Thus, it is important to consider whether a task requires deliberate or nondeliberate memory when evaluating and predicting age-related declines.

### 2.41.2.2 Short-Term and Working Memory

Short-term memory (STM) was originally suggested as the mechanism that allows temporary storage of information (Atkinson and Shiffrin, 1968). Later, Baddeley and Hitch (1974) proposed the concept of working memory (WM), which involves both the temporary storage and simultaneous manipulation of information. For example, when listening to a conversation, we must maintain individual words while concurrently relating them together into a coherent message. Aging seems to differentially affect these two functions of passive maintenance and active on-line processing. A meta-analysis by Bopp and Verhaeghen (2005) examined age differences in several verbal STM and WM tasks. Relatively small age differences were found in tasks that require simple temporary maintenance of materials. For example, forward digit span tasks, which involve storage without processing, showed a relatively modest age-related decline (d = −0.53). In contrast, tasks requiring both storage and processing showed robust age differences, and the impairment of older adults was largest when the processing component of the task became more dominant relative to the maintenance one (e.g., d = −1.01, −1.27, and −1.54, for sentence span, listening span, and computation span, respectively).

An example of a relevant study was conducted by Li (1999), who assessed age-related differences in storage and processing of verbal materials. In the STM condition of this experiment, older and younger adults were simply required to recall lists of digits. In the WM condition, subjects recalled similar lists of digits, but each digit was presented following a math problem in which subjects indicated whether the provided answer was correct or incorrect. Thus, the STM and WM tasks were similar, except that the former required only storage, whereas the latter required both storage and processing. Results showed that older adults were impaired more on the WM span than on the STM span measure. The authors conclude that older adults were more impaired, relative to younger adults, on the task that required both processing and storage than on the task that required only storage. This pattern of results seems to characterize memory not only for verbal materials but also for visuospatial materials, as shown by Vecchi and Cornoldi (1999).

### 2.41.2.3 Long-Term Memory: Semantic Versus Episodic Memory

One interesting question addressed in previous research is the degree to which there are age-related changes in memory for general knowledge (semantic memory) and whether such changes are different than those involving memory for specific events (episodes). Are older adults worse than younger adults in their ability to name the capital of Italy or to indicate whether a whale is a mammal or TOTBASHI is a word in English? Moreover, are age-related differences in the ability to respond to such questions unlike age-related differences in the ability to answer questions about specific events that tap episodic memory?

A relevant indicator for the differential patterns of performance in younger and older adults in episodic and semantic memory tasks comes from a recent large-scale study by Park et al. (2002). The study used tests of both episodic and semantic memory given to 345 people from 20 up to 92 years of age. Measures of episodic memory included visuospatial memory tests, such as the Rey visual design learning test and the Benton visual retention test, both of which required the viewing and reproduction of a specific drawing. Verbal tests involving free and cued recall of words were also included. The semantic memory tasks concentrated on verbal abilities and included the vocabulary section of the Shipley Institute of Living Scale, a synonym vocabulary test, and an antonym vocabulary test. The results, which can be seen in **Figure 1**, indicated that the age-related pattern observed was very different for episodic versus semantic memory. There was a substantial age-related decline in all measures of episodic LTM (see **Figure 1(c)**). In contrast, all three semantic memory tests showed a significant increase with age (see **Figure 1(e)**). The conclusion reached by the authors was that semantic memory does not decline – and may in fact increase – with age, whereas episodic memory exhibits a substantial age-related decline. Similar results were reported in a longitudinal study by Lövdén et al. (2004).

Several other studies also indicate that semantic memory is relatively stable over the adult lifespan. Semantic priming effects measure the amount of activation that occurs in the organized system of concepts that are connected together by associative networks (Collins and Loftus, 1975; *See* Chapter 2.28) and, as such, can provide information about age-related changes in people's structure of knowledge. Studies comparing age-related differences in semantic priming have shown either no differences or a larger semantic priming effect in the old. For example, a meta-analysis by Laver and Burke (1993) concluded that semantic priming effects showed a pattern of an increase in old age ($d = +0.10$).

One relevant study was conducted by Madden (1988), who asked older and younger adults to read sentences with one word presented at a time. The last item of each sentence, presented in all capital letters, was a target item for a lexical decision task; subjects indicated whether it was a word or a non-word as quickly as possible. Two factors were varied: one was the clarity of the target word, with some target items presented in a normal fashion and others degraded by the separation of letters by asterisks (e.g., B*O*O*K*S). The other factor was congruency, with some of the target words being congruent with the sentence context (e.g., "The accountant balanced the BOOKS"), others being incongruent (e.g., "The train went over the CLOUDS"), and still others being neutral in terms of congruence. The results showed that for nondegraded target words, neither age group responded more quickly to target words when they were congruent versus neutral in relationship with the sentences. For degraded target words, however, both age groups benefited from sentence context. Interestingly, this benefit was larger for older (117 ms) than for younger (52 ms) adults. There was also an overall context cost (i.e., the slowing of RTs for incongruous compared with neutral-context trials), which was larger for older (336 ms) than for young (167 ms) subjects. The authors conclude that these results indicate that older adults show an "increase in the influence from the semantic information that is activated automatically by a sentence context" (Madden, 1988: 171).

Another study, by Balota and Duchek (1988), manipulated the strength of the association between the prime and the target. For trials with a short delay between the prime and the target (200 ms), younger and older adults showed the same advantage in responding faster to highly associated pairs. However, when the delay between the prime and the target was longer (800 ms), older adults showed smaller benefits from the relatedness of the pairs in comparison to younger adults. Balota and Ducheck interpreted this finding to reflect intact automatic spread of activation within the semantic memory network in older adults (in the 200-ms delay condition), coupled with some decline under conditions that demand more attention (when the activation has to be maintained over a longer period of time).

There are, however, some indications that access to certain forms of semantic memory may suffer in old age. For example, it has been shown that, while they are able to name uncommon objects relatively well, older adults exhibit an impairment in naming famous people shown in pictures (e.g., Rendell et al., 2005). Overall, however, it seems that semantic memory is mostly spared of age-related changes. Episodic memory, in contrast, seems to be highly affected by advancing age; we discuss this in more detail in the next section.

## 2.41.2.4 Episodic Memory

In this section we survey research on different aspects of episodic memory changes, including memory for context versus content, the effects of intentional and incidental learning, the effects of reliance on semantic memory, performance on different episodic memory tasks, and encoding and retrieval factors.

### *2.41.2.4.1 Memory for context versus content*

One hallmark of episodic memory is its relation to time and place. That is, major characteristics of an episode involve when and where it occurred. If I am asked about what I had last night for dinner, unless I eat the same dish every night, I have to go back in my memory and use different contextual aspects of the episode, including the time (last night) and the place (a specific restaurant) where I had dinner, in order to retrieve the relevant information about the meal. Research indicates that aging impairs memory for such contextual elements as time and place to a greater degree than memory for the content of an event. For example, Spencer and Raz (1995) reviewed evidence from 46 studies. They found that the magnitude of age-related changes in context ($d = -0.90$) was significantly larger than for content ($d = -0.72$).

One representative empirical study was conducted by Puglisi et al. (1985), who compared age-related differences in memory for individual items (content) to that for occupied spatial locations (which served as context). Older and younger adults viewed target objects placed within a grid. During test, subjects were given a recall and then a recognition test over the objects and were then placed given objects in their studied location within the grid. The results showed an age-related impairment in memory for item location but not in item recognition. The authors concluded that older adults are able to recognize objects as well as younger adults but are less able to remember the spatial location of those objects (i.e., the context). Similar results were obtained by Kausler and Puckett (1980), who looked at age-related differences in memory for another contextual element – the case (upper or lower) in which a given word appeared. Their results provide support for the notion that aging has a greater effect on memory for contextual information (case of a given word) than on memory for content information (a word itself).

### *2.41.2.4.2 Intentional versus incidental learning*

A question relevant to both theory development and everyday life performance is whether age-related differences in memory are mediated by the type of learning used. Specifically, are there differences between younger and older adults in memory if, during encoding (learning), they do not expect any memory tests (as happens, e.g., when one is introduced to new people on a social occasion)? Furthermore, are these age-related differences larger or smaller than when learning occurs intentionally (such as when one learns a chapter in a textbook over which a later test is expected)?

The meta-analysis by Spencer and Raz (1995), mentioned earlier, looked at this issue and found larger age effects in studies involving memory for content and context that used intentional learning (d = −0.62) than those using incidental learning (d = −0.41). Similar results were reported in a meta-analysis by Verhaeghen et al. (1993), based on 120 studies, which found a trend toward larger age differences in list recall under intentional learning (d = −1.00) than incidental learning (d = −0.87). Finally, a meta-analysis by Johnson (2003) showed that when subjects were provided during study with advance knowledge about the upcoming test over textual information, age differences were larger (d = −0.85) than when this information was not provided (d = −0.55).

One representative study was conducted by Hogan et al. (2006). In this study, older and younger adults viewed several series of nouns and made simple judgments about each one. The word 'learn' appeared above some of the presented words, which made participants aware that memory for those specified words would be tested. Participants completed a recognition test, in which they indicated whether or not given words had been presented previously. This test included words from both the 'learn' (i.e., intentional learning) condition and words presented without 'learn' instructions (i.e., incidental learning). Results showed an interaction between age and instructions, with older adults showing greater impairment in the intentional than in the incidental learning condition. Similar results were reported by Troyer et al. (2006), who found age-related impairments in memory for people's names when encoding was intentional (the 'learn' condition), but not when encoding occurred incidentally (through physical, phonemic, or semantic processing; see Figure 3).

The results of the aforementioned studies indicate that older adults can encode information incidentally quite well relative to younger adults. However, when they have to encode information intentionally, older adults show a disadvantage relative to younger adults. This differential effect could stem from an age-related impairment in the spontaneous use of effective strategies at encoding and retrieval (e.g., Dunlosky and Hertzog, 2001). This issue is further discussed later in the chapter.

### 2.41.2.4.3 Episodic memory support by semantic memory

As previously mentioned, older adults seem to retain their semantic memory quite well. An important issue involves the degree to which this intact semantic knowledge can be used to support episodic memories. A meta-analysis by Verhaeghen et al. (1993) provides an indication that increasing categorizability (the ability to categorize new information into previously learned semantic categories) of to-be-remembered information leads to a decrease in age differences in memory (d = −0.78 and −1.07 for lists high and low in categorizability, respectively). Similarly, a more recent meta-analysis by Johnson (2003) showed larger age differences in memory for unconnected sentences (d = −0.89) than for textual passages, which are easier to connect to previously learned semantic knowledge (d = −0.62).

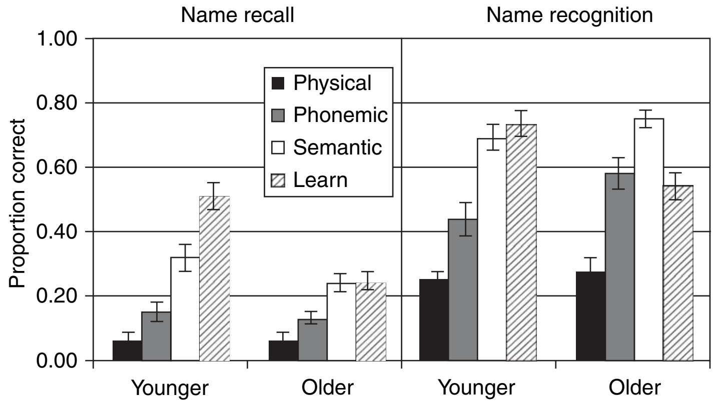


**Figure 3** Memory for names following three types of incidental learning instructions (physical, phonemic, or semantic processing) and intentional learning instructions. From Troyer AK, Häfliger A, Cadieux MJ, and Craik FIM (2006) Name and face learning in older adults: Effects of level of processing, self-generation, and intention to learn. *J. Gerontol. Psychol. Sci.* 61B: P67–P74. Copyright 2006 by The Gerontological Society of America.

One relevant study was reported by Wingfield et al. (1998), who examined age-related differences by looking at temporal patterns of free recall from categories. Older and younger adults studied lists containing words from each of several semantic categories (e.g., the animal category included bear, cat, cow, dog, and horse), until they were able to freely recall each list perfectly. At that point, participants' recall times were recorded. Results showed that nearly all responses by both younger and older adults were clustered, that is, once one word from a category was recalled, all words from that category were recalled before the participant moved to the next category. Furthermore, older adults' within-category inter-response times were similar to those of younger adults. Thus, once they were able to retrieve category names, older adults were just as fast as younger adults. However, between-category inter-response intervals were generally longer for older than for younger adults (see **Figure 4**). The authors conclude that when words are from a single semantic category, older adults' memories are just as effective as those of younger adults, indicating that older adults can in fact make use of semantic knowledge to support episodic memory performance.

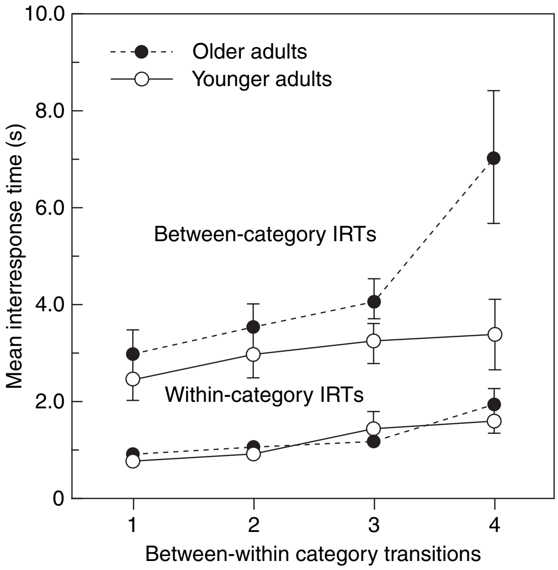


**Figure 4** Mean between-category interresponse times (IRTs) for younger and older adults over four transitions between five recalled categories, and mean within-category IRTs averaged across the five categories recalled. From Wingfield A, Lindfield KC, and Kahana MJ (1998) Adult age differences in the temporal characteristics of category free recall. *Psychol. Aging* 13: 256–266. Copyright 1998 by the American Psychological Association.

Another study, by Naveh-Benjamin (2000), assessed this issue by testing memory for related and unrelated pairs of words. After studying these pairs, participants were given a recognition, cued recall, or free recall test. Results showed that, overall, age differences were much larger in memory for unrelated word pairs than for related word pairs, and this was the case for each of the memory tasks (see **Figure 5**). The author concluded that older adults are more disadvantaged in memory for unrelated pairs but can benefit from previously learned information (schematic support, Craik, 1986; see section titled 'Attentional resource limitations') that can be utilized in related pairs to bring their episodic memory performance close to that of the younger adults.

#### 2.41.2.4.4 Retrieval from memory

As discussed, processes involved in the encoding of information are important; however, processes used to access the information (i.e., retrieval processes) are also crucial to explicit memory tasks. One factor shown to be an important facilitator at retrieval is the number and quality of the cues available. The issue of whether there are age-related differences in the ability to use those cues can be studied by employing different types of memory tasks. For example, by comparing age-related differences in a free recall task (in which no cues are provided), those in a cued-recall task (in which some cuing is provided), and those in a recognition test (in which copies of the original events serve as cues), we can assess the degree of cue utilization by younger and older adults.

**2.41.2.4.4.1 Test type** In a meta-analysis of studies on memory using different types of tests, Johnson (2003) showed (with the analysis including one mean effect size per study) that age effects were smaller in recognition tests ($d = -0.67$) than in free recall ($d = -0.82$) or cued recall ($d = -0.88$) tests. Similarly, Spencer and Raz (1995), in their meta-analysis, found larger age differences in tests of recall ($d = -1.01$; including both free and cued recall) than in recognition tests ($d = -0.57$).

An example of a study that directly compared age-related differences in recall and recognition is one by Craik and McDowd (1987). Old and young adults studied lists of phrases with target words (e.g., A body of water – pond), then completed two auditory tests, one using cued recall and the other testing recognition. In addition, during retrieval, all subjects carried out an additional reaction time (RT)

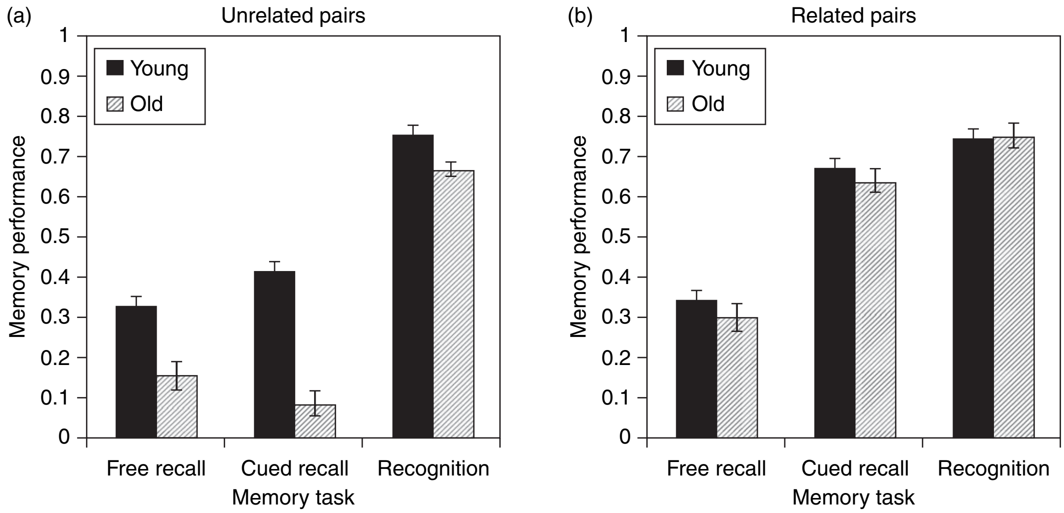


**Figure 5** Memory performance of older and younger adults for unrelated (a) and related (b) word pairs. From Naveh-Benjamin M (2000) Adult age differences in memory performance: Tests of an associative deficit hypothesis. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1170–1187. Copyright 2000 by the American Psychological Association.

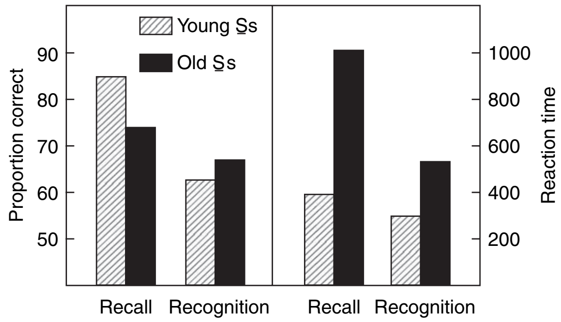


**Figure 6** Left panel: Cued recall scores (proportion correct) and recognition scores (hits minus false alarms) as a function of age; right panel: Reaction time (RT) costs (in milliseconds; mean dual-task RT minus mean baseline RT) as a function of age and retrieval task. From Craik FIM and McDowd JM (1987) Age differences in recall and recognition. *J. Exp. Psychol. Learn. Mem. Cogn.* 13: 474–479. Copyright 1987 by the American Psychological Association.

task in which they pressed one of four keys according to whether a visually presented stimulus was a vowel, consonant, odd digit, or even digit. Results showed that older adults did significantly worse than young in recall test performance but performed similarly to young on the recognition test (**Figure 6**, left). In terms of RTs on the concurrent task, younger adults performed similarly during the recall and recognition tests, whereas older adults were slower in responding to the concurrent task while they were performing recall than recognition (**Figure 6**, right). Thus, recall may be especially taxing for older adults. Similar results were obtained using recall and recognition of names (Troyer et al., 2006), showing a significant age-related decline in recall performance but no differences in recognition.

Overall, older adults seem to be impaired more on tasks requiring recall than on those using recognition. Craik and McDowd (1987) use these patterns of results to support the notion that recall requires more processing resources than does recognition, and that older adults exhibit a decline in these resources. These resources are less necessary when environmental support is provided in the form of retrieval cues (see further discussion of this issue in the section titled 'Attentional resource limitations').

***2.41.2.4.4.2 Recollection and familiarity*** Recent discussions of memory retrieval distinguish between two types of retrievals, one based on the process of recollection and the other on processes driven by familiarity (e.g., Yonelinas, 2002). Recollection is required in order to retrieve contextual and other details of an episode (e.g., when, where), whereas familiarity is based on the feeling of having previously experienced the information without remembering any specific contextual details about the event.

One major paradigm used to assess recollection and familiarity is the process dissociation procedure

(PDP; Jacoby, 1991), which generally indicates an age-related decline in retrievals based on recollection but not on familiarity (e.g., Jacoby et al., 1996; Jacoby and Hay, 1998); this conclusion was supported by Prull et al.'s summary of 13 studies (as cited by Hoyer and Verhaeghen, 2006) using this procedure. An example of such a study was conducted by Jennings and Jacoby (1993). Older and younger adults, unaware of an upcoming memory test, read aloud a list containing names of fictitious, nonfamous people. Participants then took two recognition tests, each including old and new nonfamous names, as well as real famous names. In the inclusion test, subjects were to indicate whether or not a presented name was that of a famous person. They were told, incorrectly, that any name they recognized from the earlier phase was famous, and that they should respond 'yes' to such names. In the exclusion test, they were again asked to identify famous names but were told that names they recognized from the first phase were nonfamous, so they should respond 'no' to such names. The PDP was used to calculate estimates of familiarity and of recollection for each group of subjects, based upon the idea that yes responses to studied nonfamous names could indicate either recollection or familiarity on the inclusion test but could indicate only familiarity in the absence of recollection on the exclusion test. Results showed that aging produced large declines in recollection, but familiarity estimates did not differ significantly between the groups.

Other methods used to measure recollection and familiarity include assessment of receiver operating characteristics (ROC) curves and remember/know (R/K) judgments. The former procedure involves plotting hit rates against false alarm rates at various levels of confidence, and the latter provides estimates of recollection from items judged as 'remembered' and familiarity from items judged as 'known.' Both methods, like the PDP, show a definite age-related decline in recollection, but the picture regarding familiarity is less clear. For example, Prull et al. (2006) used all three procedures and showed clear age-related differences in recollection. The different methods, however, yielded different results in regard to familiarity estimates; the R/K and ROC methods showed an age-related deficit in familiarity, whereas the PDP method did not. Light et al. (2000) reported similar patterns in a summary of relevant literature.

To summarize, there is a great deal of evidence for an age-related decline in recollection. However, such a clear conclusion cannot be drawn about familiarity, as aging effects seem to depend on the method used to measure them.

### 2.41.2.4.5 *False memory*

Memory research has been slowly moving from an interest in variables that affect accurate performance to assessment of the errors that people make in their memory reports and the sources of these errors. One area of such research involves eyewitness testimony, with studies repeatedly showing that postevent information can be mistakenly thought to have happened in the original event (e.g., Loftus and Palmer, 1974). A review article by Jacoby and Rhodes (2006) concludes that older adults are more prone than younger adults to reporting inaccurate memories. Aging seems to lead to high susceptibility to misinformation, accompanied by unawareness of this susceptibility, as older adults are relatively confident in the accuracy of their false memories (Dodson et al., 2007).

An example of a study that assessed age-related differences in susceptibility to misinformation is one by Karpel et al. (2001). In this study, older and younger adults viewed slides showing a theft and were told to try to remember the objects and events shown in the slides. Fifteen minutes after study, subjects were questioned over the slides; two of the included questions contained misleading information, mentioning objects not actually seen in the slides (called critical objects; e.g., "Did the thief pick up the bottle of Elmer's glue that was on the second desk in front of the can of Coke?" when a can of Coke was not actually shown). Five minutes later, subjects took a final test, in which they indicated whether they had seen various objects in the slides; the two critical objects were included in this test. Subjects also provided a confidence rating for each response. Results showed that older adults were less able to reject critical objects but more confident in their incorrect endorsement of those items compared with younger adults. The authors concluded that older adults are more susceptible to misleading information than are younger adults. A recent study by Roediger and Geraci (2007) showed similar susceptibility of older adults to the misinformation effect. The age-related deficit, however, was smaller for those participating in a source-monitoring test condition who needed to indicate whether the tested information was derived from the original slides, the following misleading text, both, or neither, suggesting that older adults' vulnerability to misleading information may be reduced when source information is made especially salient.


**Figure 7** Mean recognition performance as a function of group. From Balota DA, Cortese MJ, Duchek JM, et al (1999) Veridical and false memories in healthy older adults and in dementia of the Alzheimer's type. *Cogn. Neuropsychol.* 16: 361–384. Copyright 1999 by Psychology Press.

Another paradigm used in the study of false memories is the DRM (named after its creators: Deese, 1959; Roediger and McDermott, 1995). Balota et al. (1999) used this paradigm, presenting lists of items related to a critical, unpresented word. For example, 'desk,' 'computer,' 'phone,' 'books,' and so on might be presented, all being associated with the unpresented critical word 'office.' Five groups of people were tested in this study, including young adults, healthy young-old (aged 60–79 years), healthy old-old (aged 80–96 years), and adults with mild or very mild dementia of the Alzheimer's type (DAT; aged 56–91 years). At test, both groups of healthy older adults tended to falsely recall or recognize more critical words than younger adults, as indicated in **Figure 7**.

These results and others indicate that in addition to having poorer memory for the presented information, under certain conditions older adults also show an increase in intrusions and false memory more than younger adults. Some explanations for these patterns – for example, intact activation in semantic memory coupled with poor source memory – are discussed later in this chapter.

### *2.41.2.4.6 Autobiographical memory*

A question that has received more attention recently involves the degree to which people at different ages can remember events in their personal past. These autobiographical memories provide information about what people remember from their own past with respect to the frequency of these memories, their type and nature, and the ease with which they are retrieved. The procedures used in these studies are different from most of the studies mentioned so far, in that researchers assess memories that have already been established but cannot be experimentally controlled. As a result, we cannot be as confident of the authenticity of these memories. Nevertheless, these are important memories, as they provide people with a sense of continuity over their lifespan.

Research on autobiographical memories shows that an important factor, in addition to the age of the participants during retrieval, is the age at which the memories were established. Not surprisingly, several studies have shown that people tend to remember recent events. Events that occurred between the ages of 10 and 30, however, are also especially well remembered. This effect, known as the reminiscence bump, has been attributed to "privileged encoding of experiences highly relevant to an individual during a critical phase of development and consolidation of the self" (Holmes and Conway, 1999: 30).

Fromholt et al. (2003) assessed age and cohort effects on autobiographical memory by comparing life narratives produced by centenarians with those of younger seniors. Fifteen centenarians, 30 healthy younger seniors (mean age, 78 years), depressed seniors (mean age, 80 years), and demented seniors (mean age, 81 years) were interviewed, being given 15 minutes to freely tell about important events from their lives. Although the healthy younger senior group reported more memories than the other groups, all groups exhibited a reminiscence bump, with a relatively high percentage of their memories being from their teens and twenties, as can be seen in **Figure 8**. These researchers also found a reminiscence bump in a sample of 22 centenarians using the cued recall method. Interestingly, Fromholt et al. further found that historical events (such as World War II) were more often reported if they had occurred during one's bump period than if they had taken place shortly after that period. This study, and others, highlight the importance of the age at which experiences are learned, in addition to their age at retrieval.

### *2.41.2.4.7 Prospective memory*

One type of memory important in everyday life involves remembering to perform future actions. This ability, termed prospective memory (PM), is required when we must remember to show up for an appointment, to meet a friend for lunch, or to take certain medications at specific times. Results of several studies conducted on age-related differences in

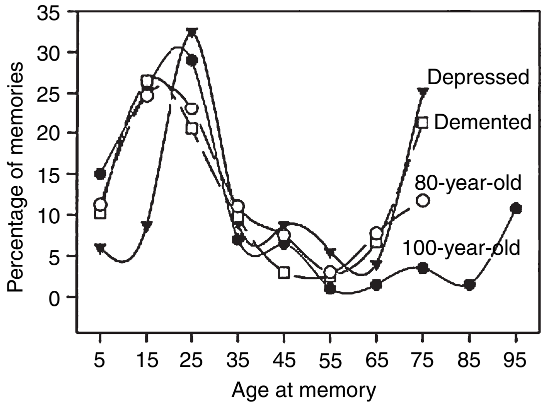


**Figure 8** The percentage of life-narrative autobiographical memories reported from each decade of life as a function of group. From Fromholt P, Mortensen DB, Torpdahl P, Bender L, Larsen P, and Rubin DC (2003) Life-narrative and word-cued autobiographical memories in centenarians: Comparisons with 80-year-old control, depressed, and dementia groups. *Memory* 11: 81–88. Copyright 2003 by Psychology Press.

PM are summarized in a meta-analysis reported by Henry et al. (2004), which indicates several patterns.

First, there seems to be a pattern indicating somewhat larger age-related declines in time-based (having to perform a specific activity at a certain hour) than in event-based (those with retrieval cues, such as having to give someone a message upon meeting him/her) PM tasks. This may be related to the former type of task relying more heavily on self-initiated processing (Craik, 1986). However, the specific results in a given task also depend on several other variables, including subject and task characteristics. For example, within event-based PM tasks, those tasks that create high strategic demands for controlled processing related to cue type, monitoring of the ongoing task, and retrieval demands, are more age sensitive than those tasks based on more automatic processing (e.g., Einstein et al., 1997; Park et al., 1997; Einstein and McDaniel, 2005). A second pattern of results within PM tasks is that older adults seem to show a larger impairment in remembering 'to' perform an action than in remembering 'which' action to perform (e.g., Cohen et al., 2001). Finally, in naturalistic studies (e.g., when people report about their performance in real-life situations, or when they have to respond to a meaningful prospective event in a laboratory situation, e.g., Rendell and Craik, 2000), rather than in typical laboratory studies, older adults do not show poorer PM than younger adults, and in some cases they even outperform younger adults. Possible reasons for this finding involve the higher relevance of ecologically valid tasks for older adults (to be discussed in the final section of the chapter) or their common use of external memory aids (e.g., writing appointments in a calendar and relying on it, as opposed to internal aids, which younger adults may use well in laboratory situations).

## 2.41.3 Theoretical Views

Considering the wealth of empirical evidence related to age-related changes in memory, some of which are reviewed above, it is not surprising that various theoretical accounts have been offered to explain the underlying mechanisms and processes that give rise to the different phenomena. Some of these mechanisms are more distal and relate to phenomena in cognitive aging in general, whereas others are more specific to age-related changes in memory. Following, we outline some of the major approaches and the way they explain the phenomena at hand. We then suggest an integrated approach.

### 2.41.3.1 General Mechanisms: Processing Resources Limitations

Several suggested frameworks claim that age-related changes in memory in particular, and in cognition in general, are the result of a decline in mental processing resources associated with age. These resources may be related to attention, speed, or capacity.

#### *2.41.3.1.1 Attentional resource limitations*

Several researchers (e.g., Hasher and Zacks, 1979; Craik and Byrd, 1982; Craik, 1983, 1986) have suggested that the pool of attentional resources needed to perform a given task is reduced in old age, and that this reduction is the cause of many age-related changes in cognitive tasks. This view predicts that older adults will be especially impaired on difficult tasks that require a significant amount of attentional resources. Evidence from Craik and Byrd (1982), Craik (1983, 1986), Rabinowitz et al. (1982), and Craik and McDowd (1987) is consistent with this notion, suggesting that a shortage of available attentional resources in older adults results in poorer memory because effortful cognitive operations, such as elaboration and effortful retrieval, require substantial attentional resources.

Furthermore, whereas recurring aspects of items can be encoded in a relatively automatic fashion, changing contextual elements of a situation demand a large amount of attentional resources. Thus, when these attentional resources are low – as in old age – there will be a tendency to encode items in terms of their general, stereotyped features, resulting in poor memory for the event. Results from several studies are consistent with this notion (e.g., Rabinowitz et al., 1982; Hess et al., 1989; Hashtroudi et al., 1990). Moreover, Craik and Byrd (1982) and Craik and Simon (1980) have shown that general retrieval cues (which require fewer attentional resources, as measured by secondary task performance) are relatively more effective for older subjects, whereas more specific contextual cues are relatively more effective for young adults.

Similar patterns have been reported for retrieval, as well. For example, as mentioned earlier, Craik and McDowd (1987) showed that older adults' performance was poorer on cued recall than on recognition tasks compared with younger adults. Such results can be interpreted in terms of the amount of attentional resources required by each type of task (as indicated by secondary task performance); cued recall requires substantial resources to search for the target word, whereas recognition, in which subjects are provided with a copy of the original target, requires fewer attentional resources.

Another line of research supporting the reduced attentional resources notion involves the effects of divided attention (DA) on memory. Several studies indicate that under DA conditions involving memory, older adults demonstrate a larger reduction in the combined performance on both the primary and the secondary tasks, relative to younger adults (e.g., Anderson et al., 1998; Li et al., 2001). Furthermore, several studies have found that younger adults whose available attentional resources are reduced by performing a secondary task exhibit a pattern of memory performance decline similar to that of older adults (e.g., Craik and Byrd, 1982; Rabinowitz et al., 1982; Jennings and Jacoby, 1993; Chen and Blanchard-Fields, 2000).

The notion of an age-related decline in attentional resources is in line with other memory impairments described in the previous sections. For example, the larger age-related decline in working memory than in short-term memory (e.g., Bopp and Verhaeghen, 2005) could be caused by a greater demand on attentional resources by the former. Likewise, explicit memory tasks require more attentional resources at retrieval than do implicit memory tasks, which usually do not require deliberate memory search. Furthermore, the encoding and explicit retrieval of contextual details and processes involved in recollection require more attentional resources than do familiarity responses (e.g., Troyer et al., 1999; Gardiner et al., 2006).

Craik (1986) elaborated on the notion of attentional resources to make the distinction between tasks that rely on environmental support and those that require self-initiation. Tasks that rely more on environmental support – for example, recognition memory, in which a copy of the presented stimulus is provided as a cue – require less self-initiation/attentional resources and hence should not show large age-related declines. In contrast, tasks that require more self-initiation, such as free recall, should show larger age decrements. Both notions are in line with empirical evidence (e.g., Craik and McDowd, 1987).

A related view of the age-related decline in memory addresses the distinction between controlled and automatic processes. According to this view, older adults will show a decline in memory tasks that require controlled, effortful processes but will exhibit no or only a small decline in tasks mediated by more automatic processes (Hasher and Zacks, 1979). This suggestion relates to the depleted attentional resources view, as tasks based on automatic processes should not require substantial attentional resources, whereas tasks that require controlled effortful processes should draw heavily on attentional resources; thus, age-related impairments should be largest on tasks that demand controlled processing. Such a position can explain why implicit memory, for example, seems to be intact in older adults, as it is driven largely by automatic processes. Likewise, recall tasks, which require relatively controlled processes, should be more affected by aging than recognition tasks. The controlled-automatic distinction is also consistent with results of studies suggesting that older adults' episodic memory impairments may be partially the result of the failure to spontaneously use effective strategies at encoding and at retrieval. Interestingly, these studies suggest that older adults can improve their performance by receiving appropriate instructions to use strategy, although this generally does not eliminate age differences altogether (e.g., Verhaeghen et al., 1992; Dunlosky and Hertzog, 2001; Naveh-Benjamin et al., 2005).

While the distinction between tasks based on automatic and controlled processes seems to have heuristic value, there are problems regarding the definition of each type of process and in task analyses to determine which processes are involved in a given task. Similarly, some researchers (e.g., Salthouse, 1988; 1991b) claim that the notion of attentional resources is too vague, at a framework level only, without enough details to be considered a model or a theory and is not well operationally defined.

To summarize, although there have been criticisms of the reduced attentional capacity framework on the grounds of vagueness, it seems to provide a heuristic functional explanation to age-related decline in memory performance. Further studies should employ different tasks to assess the construct validity of attentional resources, as well as to specify the mechanisms underlying depleted resources, potentially in terms of specific brain-related changes (see Carpenter et al., 1999).

#### 2.41.3.1.2 Speed of processing limitations

Another idea involving limited resources of older adults is in terms of the speed with which mental processes can be carried out. Several researchers have suggested that the execution of mental processes slows down in old age (e.g., Birren, 1965; Birren et al., 1979). Additionally, Salthouse (1996) suggested that slowing of basic information processing at the microlevel may result in poorer performance at a more macrolevel. For example, if a task involves several processing components, and the first few are slowed down with age, the input of these components will not arrive in time to feed later processing units, resulting in failure to complete the task. Using tools of multivariate statistics, such as path analysis and large-scale psychometric studies, Salthouse (1996) has shown that measures of basic speed mediate a significant age-related variance in several memory tasks. Verhaeghen and Salthouse (1997) conducted a meta-analysis of cross-sectional studies and found, for example, that speed can account for over 70% of age-related variance in episodic memory measures.

Although the slowing down notion seems reasonable, future studies using the speed approach should provide for a better understanding of the relations of speed to the specific differential decline patterns characterizing memory and aging. For example, the approach must be able to explain why intentional learning is more harmed by age than is incidental learning, why semantically related information is better remembered by older adults than is unrelated information, why context memory is especially poor in older age, and why recollection is more affected by age than is familiarity.

#### 2.41.3.1.3 Capacity (working memory) limitations

Some researchers (e.g., Welford, 1980; Parkinson, 1982; Hasher and Zacks, 1988; Puckett and Lawson, 1989) claim that reduced WM capacity is a major factor in age-related declines in many memory and other cognitive tasks. The notion is that to engage in any online processing required for different memory tasks – for example, encoding of spoken sentences – people must use processes to coordinate the interplay between temporary storage of the information and its integration into a cohesive message (Baddeley, 1986). According to this idea, older adults possess less efficient control processes, making, for example, the encoding of text more demanding and difficult (e.g., Light and Albertson, 1988). In support of this notion, Salthouse (1991a) has shown that when performance on measures of WM is statistically controlled, age-related declines in memory tasks are reduced by a substantial amount.

Whereas the original notion of WM capacity was somewhat similar to that of depleted attentional resources, mentioned above, more recently, more specific executive processes involved in WM have been suggested as the loci of memory decline in older adults. In particular, Hasher and Zacks (1988) and Zacks and Hasher (1997) claimed that older adults have a special problem in the recruitment of efficient inhibitory processes, making it difficult to block irrelevant information from entering WM. In this sense, it is not necessarily that WM capacity is smaller in old age but that it is cluttered with irrelevant information that was not appropriately filtered. This, in turn, hinders efficient processing – such as that involved in encoding and retrieval operations – of ongoing information. Support for the inhibition notion comes from studies showing, for example, that in contrast to young adults, irrelevant information is still held in older adults' WM despite being disconfirmed (e.g., Hartman and Hasher, 1991). Chapter 3.28 in this volume discusses such failures in terms of an age-related decrease in frontal lobe efficiency. Other relevant executive processes are those involved in task switching. Recent results indicate that older adults have difficulty rapidly switching between different aspects of a given task (e.g., Mayr et al., 2001).

The recent trend toward assessing the specific WM processes that decline as people age seems to be a fruitful direction that should be followed up in future research. This avenue of study could potentially explain one underlying root of the age-related decline in general cognition and in memory processes in particular.

Overall, although the above suggestions for the mediating role of age-related decline in processing resources in cognition are reasonable, for some their direct effects on memory performance have not yet been demonstrated. Further studies are needed to demonstrate empirically the precise way in which these different suggestions of decline in processing resources are responsible for the complex pattern of both decline and stability in memory in old age.

### 2.41.3.2 Memory-Specific Mechanisms

Whereas the above views are more general and relate not only to performance on memory tasks but also to cognitive processes in general, there have been some attempts to specify the particular mechanisms involved in age-related patterns in memory tasks.

#### *2.41.3.2.1 The source-contextual deficit approach*

According to this approach, older adults have problems at retrieval in distinguishing between different sources of original events (e.g., Johnson et al., 1993). In the eyewitness memory paradigm, for example, the claim made is that older adults, relative to young ones, cannot distinguish between the original information and related information that is subsequently presented. This idea can be extended to context in general, with the claim that one reason for older adults' memory decline is their inability to remember different aspects of the encoding context, including the time when an event took place, where it happened, the associated internal psychological context, and the social circumstances involved. The notion is that young people can better encode these contextual details, which can later serve as retrieval cues when a particular episode, or its components, must be remembered.

The source-contextual deficit suggestion is in line with studies reviewed earlier in this chapter that indicate a differential age-related decline in episodic versus semantic memory, as only the former relies on specific contextual details. This may help to explain the findings on eyewitness testimony, discussed above in the false memory section, in that older adults may fail to remember the source of specific information, thus leaving them susceptible to misinformation. Furthermore, as reviewed earlier, older adults show a particularly large deficit in memory for contextual/source details relative to their memory for the content/focal events. Finally, free and cued recall are more affected by contextual details than is recognition memory (e.g., Godden and Baddeley, 1975, 1980), and as mentioned earlier, older adults show more of a decline on recall tests.

#### *2.41.3.2.2 Associative-binding deficit approach*

Another suggestion in the literature is that older adults have a special problem in associating/binding different components of an episode into a cohesive unit (Chalfonte and Johnson, 1996; Mitchell et al., 2000; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003). Naveh-Benjamin termed this the associative deficit hypothesis (ADH), which suggests that older adults have a relatively intact mechanism to encode and retrieve components of an episode but have a special problem in binding together the different components into a cohesive episode and in explicitly retrieving these associations. The ADH is more general than the source/context deficit notion, suggesting that the older adults have problems whenever explicit memory requiring the binding together of different components is involved. These bindings could be between an item and its context or between two items or objects.

The ADH is supported by evidence showing that older adults perform significantly more poorly than young adults on tasks requiring memory for associations but that age differences are relatively small when memory for individual components is tested. For example, Naveh-Benjamin et al. (2004) presented young and old participants with faces paired with names, with the task of trying to learn the names, the faces, and the associations between the name and the face in each pair. Three recognition tests were given. On the name test and the face test, participants were presented with either two names or two faces, respectively, and were asked to choose the stimulus that they had seen at study. The third test was an associative recognition test, in which subjects chose between two previously presented names that belonged with a given face or between two previously presented faces that belonged with a given name. Results, which can be seen in **Figure 9**, showed no age-related difference in name recognition and only a small age-related difference in face

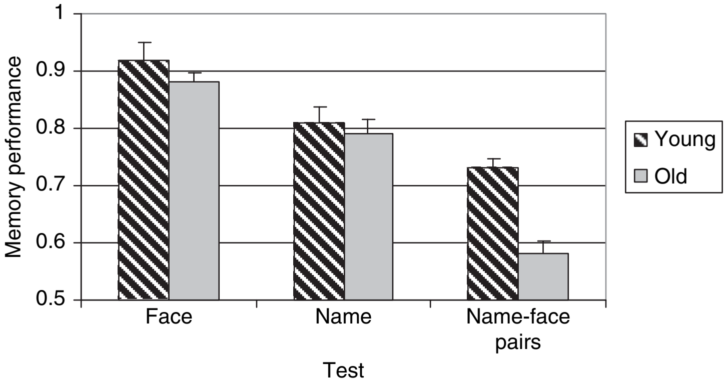


**Figure 9** Memory performance in recognition of faces, names, and name–face pairs, as a function of age group. From Naveh-Benjamin M, Guez J, Kilb A, and Reedy S (2004) The associative memory deficit of older adults: Further support using face-name associations. *Psychol. Aging* 19: 541–546. Copyright 2004 by the American Psychological Association.

recognition but a large age-related decline in the associative tests of names and faces. This associative deficit has been observed using various types of stimuli, including associations between Snodgrass drawings and their arbitrary colors (Chalfonte and Johnson, 1996; Mitchell, et al., 2000), pairings of words (Naveh-Benjamin, 2000, Experiment 2; Castel and Craik, 2003; Light et al., 2004; Healy et al., 2005), pairings between words and their fonts (Naveh-Benjamin, 2000, Experiment 3), and pairings of pictures (Naveh-Benjamin et al., 2003).

This ADH can accommodate several of the results reviewed earlier. For example, implicit memory should not be affected as much by aging as explicit memory, as it requires to a much lesser degree explicit retrieval processes involved in recovering information about binding of elements in an episode. In addition, semantic memory should be affected to a lesser degree than episodic memory because it does not require the specific binding of information to a place and time. There are also some indications that part of the deficit is due to the inability of older adults to spontaneously produce and efficiently use adequate associative strategies to bind together information. Studies inducing the use of a connective strategy (a sentence or an interactive mental image) during encoding and during retrieval have shown an increase in older adults' performance on memory tasks requiring associative information, in some cases more so than younger adults (Naveh-Benjamin et al., 2005; Naveh-Benjamin et al., 2007).

#### 2.41.3.2.3 *Recollection deficit approach*

This hypothesis, for which empirical results were cited earlier in this chapter (e.g., Jacoby et al., 1996; Jacoby and Hay, 1998), claims that older adults' memory deficit is largely a result of their inability during retrieval to access the details of an episode, resulting in recollection failure. According to this suggestion, the ability to remember via familiarity – for example, to notice that something was already presented before, without remembering detailed information about the event – is left mostly intact in old age. This hypothesis (e.g., Jacoby, 1999) is supported by many studies that used the process dissociation paradigm or the R/K procedure, which were reviewed earlier in the chapter. The hypothesis can explain the relatively adequate performance of older adults in implicit memory tasks and in those requiring semantic memory. In both cases, no detailed conscious recollection of the original event is required. Likewise, source memory, which requires recollection of detailed information, is especially prone to the effects of age.

### 2.41.3.3 An Integrated View

The above-suggested source-contextual, associative-binding, and recollection deficit hypotheses seem to have different emphases. For example, the source-contextual and the associative-binding approaches emphasize failure more at the encoding phase, whereas the recollection perspective deals more with processes that happen at retrieval. In addition, the paradigms used by each of the approaches are quite different. Nevertheless, there are some fundamental similarities between the three approaches. The common assumption held by all three is that age-related memory declines are caused by a lack of efficient episodic encoding and retrieval of detailed bound information. Difficulty in encoding specific features of an episode and in establishing associations among those features may result in, for example, the inability of an older adult to recall the name of a new acquaintance upon encountering that person, despite the fact that he or she may look familiar. This difficulty may be caused by a failure of conscious recollection of the contextual details or circumstances (e.g., time and place) regarding the original encounter with this person and/or to the fact that this person and not someone else they met on the same occasion is named, for example, George. The poor encoding of source-contextual features, as well as a reduced ability to bind together the different features of the event and its contextual elements, will increase the chances of a conscious recollection failure of the detailed information at the retrieval phase. In this sense, the three approaches are somewhat similar and complement each other.

Such an integrated approach can explain several of the empirical lines of evidence for age-related memory changes reviewed earlier in this chapter. For example, the fact that semantic memory is held relatively intact during adulthood and old age could be a result of the encoding of contextual details and their recollection being crucial in episodic – but not in semantic – memory. This is because the multiple repetitions of facts in semantic memory increase their familiarity, which is relatively intact with age. Such an integrated view can also explain the relatively minor age-related decrements in implicit memory, since this system is based more on familiarity and fluency and does not require detailed encoding and binding of contextual details or the recollection of specific encoded features (e.g., Roediger, 1990; Schacter et al., 1993).

This integrated approach can also explain age-related changes in false memory. As we reviewed earlier in the chapter, older adults tend to show an increase in the retrieval of incorrect memories. This finding could be caused by an age-related reduction in the ability to bind together bits of information from the original event and to keep these bindings separate from information included in the postevent episode. If during retrieval, older adults cannot recollect the contextual details of the original event, they may integrate bits of later-learned information into their memory of the original event, mistaking, for example, a person viewed in a mugshot at a police station for the true culprit. Similarly, in the DRM paradigm of false memory, older adults tend to recall or recognize, more so than young, the critical lure – the related event that did not happen. According to the suggested view here, this may be a consequence of their inability to bind together the content words and the context – either external (presented) or internal (generated). When the critical word is later presented in a recognition test, the reduced ability of older adults to recall contextual features related to the critical and target words, coupled with feelings of familiarity, could lead to false recognition.

One potential task of future research on memory and aging is to test specific predictions based on this integrated approach. For example, it seems reasonable that the more features and their bindings involved in an event, the more difficult it would be for older adults to encode and bind together the features and to recollect them during retrieval. Furthermore, if some of the features, for example, the contextual elements, are common to the different episodes, this might result in a nondistinct contextual encoding that will make recollection by older adults more difficult later on (see Hunt and McDaniel, 1993, for a discussion of distinctiveness). On the other hand, if the features of each event are unique and distinctive from each other, older adults might be better able to bind together and to recall those features (e.g., Johnson et al., 1995; Degl'Innocenti and Backman, 1996).

Such a unified view can be incorporated with the depleted resources framework reviewed earlier to provide the following hypothesis: It may be that the lack of resources in older adults – for example, reduced attentional resources both at encoding and at retrieval (e.g., Anderson et al., 1998; Naveh-Benjamin et al., 2005) – could mediate the source/context/binding failure at encoding, as well as recollection failure at retrieval. This suggestion makes several assumptions. First, the encoding of contextual elements and the binding together of features is more effortful and requires more resources than the encoding of the focal elements and each feature separately (Troyer, et al., 1999; Castel and Craik, 2003; but see different results by Naveh-Benjamin, et al., 2003). Second, the retrieval and recollection of bound and contextually detailed information requires more attentional resources than that of contextually impoverished information (e.g., Troyer, et al., 1999). Future studies could assess this suggestion, for example, by measuring the attentional resources associated with different types of feature, context, and associative (feature-binding) encoding and retrieval.

## 2.41.4 Further Issues

### 2.41.4.1 Uniqueness of Age-Related Memory Changes in General Cognitive Decline

One question that has consequences for the interpretation of age-related differences in memory is whether these differences constitute unique declines in the memory system or whether they are just a manifestation of more general changes in cognition. One statistical control approach to studying this question was employed by Salthouse et al. (2002), who assessed performance of different age groups on several variables, some related to memory and others to other cognitive tasks. Salthouse et al. then looked at the variance accounted for by age in a given memory task while statistically controlling the variance in some of the other cognitive tasks. The results showed that the proportion of age-related variance in a free recall memory task declined from 30% to less than 20% after statistically controlling the variance in a block design task (taken from the WAIS III, Wechsler, 1997) and to less than 5% after statistically controlling the variance in performance on the digit symbol task (also taken from the WAIS III). Similar findings were shown by Siedlecki et al. (2005), who administered a battery of different cognitive tests to 330 adults between the ages of 18 and 89, along with several tests of source memory. Using structural equation modeling, the researchers found no indication of a unique age-related variance on source memory only. Similar results have been obtained for other episodic memory measures (e.g., Salthouse et al., 2006). Such findings imply that age-related effects on memory measures and on other cognitive variables are not independent of each other.

These results raise interesting questions regarding the different approaches to studying the effects of age on memory and their respective outcomes and contributions. One approach, discussed throughout most of this chapter, is experimental, assessing the effects of specific manipulations on the memory performance of young and older adults. This approach reveals a variety of differential effects of aging on memory. The approach discussed in the previous paragraph, based on psychometric studies of individual differences, looks simultaneously at relationships between age and several memory and cognitive indices and often shows that the effects of age on memory are not unique but are shared with other cognitive variables. It seems that the research on age-related differences in memory would benefit from the integration of both approaches in order to provide a better understanding of the absolute changes in different tasks on one hand and the degree to which differences in one condition are statistically independent from differences in another condition.

### 2.41.4.2 Positive Modulators of Older Adults' Episodic Memory Performance

Even though older adults seem to show poorer episodic memory than younger adults, there are nevertheless variables that seem to positively modulate older adults' episodic memory. For example, studies indicate that older adults tend to remember emotional material relatively well, often performing just as well as younger adults on positively valenced material. This has been found both in working memory (e.g., Mikels et al., 2005) and in long-term episodic memory (see, e.g., Carstensen et al., 2006, for a review). The suggestion raised (e.g., Carstensen et al., 1999) is that socioemotional regulation becomes more important as people age, changing their motivation, which then leads to successful encoding and retrieval of emotional information, especially when it is positive. Such changes in priorities also result in the tendency to remember autobiographical events more positively as people age (see, e.g., Mather and Carstensen, 2005 for a review).

In addition, although older adults are relatively impaired in memory for verbatim information, they remember well the gist of information and add their interpretation to it, creating a richer narrative. For example, studies regarding memory of information presented in stories indicate that older adults do well on remembering the underlying messages and gist of the stories (e.g., Adams et al., 1997; Stine-Morrow et al., 2004).

Finally, time of day seems to make a difference in memory performance, with older adults doing relatively well when they are tested in their 'prime' time – in the morning. Yoon et al. (1999) administered the Morningness-Eveningness Questionnaire (MEQ) to over 2000 older and younger adults and report that approximately 75% of the older sample, but less than 10% of the young sample, could be classified as morning types; conversely, very few older adults and nearly 40% of younger adults were evening types. Interestingly, May et al. (2005) found that evening-type younger adults and morning-type older adults performed better on an explicit memory task – but worse on an implicit task – during their peak hours. Furthermore, it has been suggested that different circadian patterns in young and old can artificially enhance age-related declines in memory (May et al., 1993). This occurs because participants are often tested in the afternoon (the convenient time for the young research assistants), when younger adults, by their arousal patterns, are performing at their highest levels. When testing is done in the morning, older adults often perform quite well, for example, on working memory tasks (e.g., West et al., 2002).

#### 2.41.4.3 Negative Modulators of Older Adults' Episodic Memory Performance

There are several other factors that may have inflated some of the reviewed age-related declines in episodic memory. For example, older adults might not be as motivated as younger students to perform at their best in laboratory situations. The materials used in many episodic memory tasks (such as lists of words) may seem contrived and of little relevance to older adults, therefore decreasing their motivation to do well (e.g., Henry et al., 2004). This may be one reason why they perform relatively well on semantic memory tasks, which by their nature employ more ecologically valid, relevant, and interesting materials.

Another mediating factor might be a lack of recent practice in testing situations and the anxiety produced by such testing in the laboratory. Older adults usually do not frequently encounter explicit testing situations in their lives, as do younger adults, who are often university students and who take tests very frequently. This lack of recent testing practice may put older adults at a disadvantage. In addition, it may create higher anxiety in older adults (but see Birren, 1964), which in turn is known to reduce cognitive performance (Wetherell et al., 2002). Although this factor may not straightforwardly explain interaction effects – cases where older adults are doing worse on one episodic task than on another – it can increase the overall differences observed between young and old. An intriguing demonstration of the potentially mediating effect of anxiety on age-related differences in memory is a study by Rahhal et al. (2001), who found that age differences in recognition memory were eliminated when the terms 'memory' and 'testing' were completely omitted from task instructions. One interpretation of these results is that the latter condition did not induce the usual level of anxiety in older adults, which, in turn, helped them to perform well. Alternatively, knowing that they are in a memory experiment might evoke older adults' negative stereotypes about memory and aging, which might negatively affect their performance. These stereotypes are presumably not induced when the task does not seem related to memory.

Finally, as we mentioned at the outset, most of the studies reviewed in this chapter used a cross-sectional design and, as such, might have been affected by various factors, most notably, cohort effects (e.g., Schaie, 2000). It is important to note that, when data on the same memory phenomenon are collected using both cross-sectional and longitudinal designs, age-related differences tend to be smaller in longitudinal studies, with peak performance later in life (e.g., Rönnlund et al., 2005). Thus, the patterns of decline reported in this chapter, which are mostly based on cross-sectional designs, may be an overestimation of actual age-related declines in memory.

## 2.41.5 Summary

The evidence reviewed in this chapter indicates interesting differential patterns of development in adulthood and old age that depend on different factors, including the task and the memory type involved. Whereas implicit and semantic memory show little decline with age, tasks based on episodic memory, especially those that require the encoding and the explicit retrieval of detailed bound information about a given event, show appreciable decline. It seems that as long as the task does not require remembering specific details, and as long as performance can be supported by previous knowledge or environmental cues, older adults do quite well.

Several theoretical accounts at different levels of generality have been suggested to explain the age-related patterns of memory development, and especially of episodic memory deficits. A unified approach characterizes old age as being associated with a lack of detailed encoding and binding together of both contextual and focal components of an episode, coupled with difficulty in accessing and recollecting these details during retrieval, possibly because of the high demand of these processes for attentional resources. Such an approach may serve as a departure point to further investigate these important issues using both the manipulative and the psychometric approaches to advance our knowledge of age-related changes in memory.

## References


Adams C, Smith MC, Nyquist L, and Perlmutter M (1997) Adult age-group differences in recall for the literal and interpretive meanings of narrative text. *J. Gerontol. B Psychol. Sci.* 52B: P187–P195.

Anderson ND, Craik FIM, and Naveh-Benjamin M (1998) The attentional demands of encoding and retrieval in younger and older adults: 1. Evidence from divided attention costs. *Psychol. Aging* 13: 405–423.

Atkinson RC and Shiffrin RM (1968) Human memory: A proposed system and its control processes. In: Spence KW and Spence JT (eds.) *The Psychology of Learning and Motivation,* Vol. 2, pp. 89–105. New York: Academic Press.

Baddeley A (1986) *Working Memory*. New York: Clarendon Press/Oxford University Press.

Baddeley AD and Hitch G (1974) Working memory. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 8, pp. 47–89. New York: Academic Press.

Balota DA and Duchek JM (1988) Age-related differences in lexical access, spreading activation, and simple pronunciation. *Psychol. Aging* 3: 84–93.

Balota DA, Cortese MJ, Duchek JM, et al (1999) Veridical and false memories in healthy older adults and in dementia of the Alzheimer's type. *Cogn. Neuropsychol.* 16: 361–384.

Birren JE (1964) *The Psychology of Aging*. Englewood Cliffs, NJ: Prentice-Hall.

Birren JE (1965) Age changes in speed of behavior: Its central nature and physiological correlates. In: Welford AT and Birren JE (eds.) *Behavior, Aging, and the Nervous System: Biological Determinants of Speed of Behavior and Its Changes with Age*, pp. 191–216. Springfield, IL: Charles C. Thomas.

Birren JE, Woods AM, and Williams MV (1979) Speed of behavior as an indicator of age changes and the integrity of the nervous system. In: Hoffmeister F and Muller C (eds.) *Brain Function and Old Age*, pp. 10–44. New York: Springer-Verlag.

Bopp KL and Verhaeghen P (2005) Aging and verbal memory span: A meta-analysis. *J. Gerontol. Psychol. Sci.* 60B: P223–P233.

Carpenter PA, Just MA, Keller TA, Eddy WF, and Thulborn KR (1999) Time course of fMRI-activation in language and spatial networks during sentence comprehension. *Neuroimage* 10: 216–224.

Carstensen LL, Isaacowitz DM, and Charles ST (1999) Taking time seriously: A theory of socioemotional selectivity. *Am. Psychol.* 54: 165–181.

Carstensen LL, Mikels JA, and Mather M (2006) Aging and the intersection of cognition, motivation, and emotion. In: Birren JE and Schaie KW (eds.) *Handbook of the Psychology of Aging*, pp. 343–362. Amsterdam: Elsevier.

Castel AD and Craik FIM (2003) The effects of aging and divided attention on memory for item and associative information. *Psychol. Aging* 18: 873–885.

Chalfonte BL and Johnson MK (1996) Feature memory and binding in young and older adults. *Mem. Cogn.* 24: 403–416.

Chen Y and Blanchard-Fields F (2000) Unwanted thought: Age differences in the correction of social judgments. *Psychol. Aging* 15: 475–482.

Cohen A-L, West R, and Craik FIM (2001) Modulation of the prospective and retrospective components of memory for intentions in younger and older adults. *Aging Neuropsychol. Cogn.* 8: 1–13.

Collins AM and Loftus EF (1975) A spreading-activation theory of semantic processing. *Psychol. Rev.* 82: 407–428.

Craik FIM (1983) On the transfer of information from temporary to permanent memory. *Philos. Trans. R. Soc. Lond. B* 302: 341–359.

Craik FIM (1986) A functional account of age differences in memory. In: Klix F and Hagendorf H (eds.) *Human Memory and Cognitive Capabilities: Mechanisms and Performance*, pp. 409–422. Amsterdam: North-Holland and Elsevier.

Craik FIM and Byrd M (1982) Aging and cognitive deficits: The role of attentional resources. In: Craik FIM and Trehub SE (eds.) *Aging and Cognitive Processes*, pp. 191–211. New York: Plenum.

Craik FIM and McDowd JM (1987) Age differences in recall and recognition. *J. Exp. Psychol. Learn. Mem. Cogn.* 13: 474–479.

Craik FIM and Simon E (1980) Age differences in memory: The roles of attention and depth of processing. In: Poon LW, Fozard JL, Cermak LS, and Thompson LW (eds.) *New Directions in Memory and Aging: Proceedings of the George A. Talland Memorial Conference*. Hillsdale, NJ: Erlbaum.

Deese J (1959) On the prediction of occurrence of particular verbal intrusions in immediate recall. *J. Exp. Psychol.* 58: 17–22.

Degl'Innocenti A and Backman L (1996) Aging and source memory: Influences of intention to remember and associations with frontal lobe tests. *Aging Neuropsychol. Cogn.* 3: 307–319.

Dodson CS, Bawa S, and Slotnick SD (2007) Aging, source memory, and misrecollections. *J. Exp. Psychol. Learn. Mem. Cogn.* 33: 169–181.

Dunlosky J and Hertzog C (2001) Measuring strategy production during associative learning: The relative utility of concurrent versus retrospective reports. *Mem. Cogn.* 29: 247–253.

Einstein GO and McDaniel MA (2005) Prospective memory: Multiple retrieval processes. *Curr. Direct. Psychol. Sci.* 14: 286–290.

Einstein GO, Smith RE, McDaniel MA, and Shaw P (1997) Aging and prospective memory: The influence of increased task demands at encoding and retrieval. *Psychol. Aging* 12: 479–488.

Fleischman DA, Wilson RS, Gabrieli JDE, Bienias JL, and Bennett DA (2004) A longitudinal study of implicit and explicit memory in old persons. *Psychol. Aging* 19: 617–625.

Fromholt P, Mortensen DB, Torpdahl P, Bender L, Larsen P, and Rubin DC (2003) Life-narrative and word-cued autobiographical memories in centenarians: Comparisons with 80-year-old control, depressed, and dementia groups. *Memory* 11: 81–88.

Gardiner JM, Gregg VH, and Karayianni I (2006) Recognition memory and awareness: Occurrence of perceptual effects in remembering or in knowing depends on conscious resources at encoding, but not at retrieval. *Mem. Cogn.* 34: 227–239.

Godden DR and Baddeley AD (1975) Context-dependent memory in two natural environments: On land and underwater. *Br. J. Psychol.* 66: 325–331.

Godden DR and Baddeley AD (1980) When does context influence recognition memory? *Br. J. Psychol.* 71: 99–104.

Hartman M and Hasher L (1991) Aging and suppression: Memory for previously relevant information. *Psychol. Aging* 6: 538–551.

Hasher L and Zacks RT (1979) Automatic and effortful processes in memory. *J. Exp. Psychol. Gen.* 108: 356–388.

Hasher L and Zacks RT (1988) Working memory, comprehension, and aging: A review and a new view. In: Bower GH (ed.) *The Psychology of Learning and Motivation: Advances in Research and Theory,* vol. 22, pp. 193–225. San Diego CA: Academic Press.

Hashtroudi S, Johnson MK, and Chrosniak LD (1990) Aging and qualitative characteristics of memories for perceived and imagined complex events. *Psychol. Aging* 5: 119–126.

Healy MR, Light LL, and Chung C (2005) Dual-process models of associative recognition in young and older adults:

Evidence from receiver operating characteristics. *J. Exp. Psychol. Learn. Mem. Cogn.* 31: 768–788.
Henry JD, MacLeod MS, Phillips LH, and Crawford JR (2004) A meta-analytic review of prospective memory and aging. *Psychol. Aging* 19: 27–39.
Hess TM, Donley J, and Vandermaas MO (1989) Aging-related changes in the processing and retention of script information. *Exp. Aging Res.* 15: 89–96.
Hogan MJ, Kelly CAM, and Craik FIM (2006) The effects of attention switching on encoding and retrieval of words in younger and older adults. *Exp. Aging Res.* 32: 153–183.
Holmes A and Conway MA (1999) Generation identity and the reminiscence bump: Memory for public and private events. *J. Adult Dev.* 6: 21–34.
Hoyer WJ and Verhaeghen P (2006) Memory aging. In: Birren JE and Schaie KW (eds.) *Handbook of the Psychology of Aging*, pp. 209–232. Amsterdam: Elsevier.
Hunt RR and McDaniel MA (1993) The enigma of organization and distinctiveness. *J. Mem. Lang.* 32: 421–445.
Jacoby LL (1991) A process dissociation framework: Separating automatic from intentional uses of memory. *J. Mem. Lang.* 30: 513–541.
Jacoby LL (1999) Ironic effects of repetition: Measuring age-related differences in memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 25: 3–22.
Jacoby LL and Hay JF (1998) Age-related deficits in memory: Theory and application. In: Conway MA, Gathercole SE, and Cornoldi C (eds.) *Theories of Memory*, vol. 2, pp. 111–134. Hove, UK: Psychology Press.
Jacoby LL, Jennings JM, and Hay JF (1996) Dissociating automatic and consciously-controlled processes: Implications for diagnosis and rehabilitation of memory deficits. In: Herrmann DJ, McEvoy C, Hertzog C, Hertel P, and Johnson MK (eds.) *Basic and Applied Memory Research: Theory in Context,* vol. 1, pp. 161–193. Hillsdale, NJ: Erlbaum.
Jacoby LL and Rhodes MG (2006) False remembering in the aged. *Curr. Direct. Psychol. Sci.* 15: 49–53.
Jennings JM and Jacoby LL (1993) Automatic versus intentional uses of memory: Aging, attention, and control. *Psychol. Aging* 8: 283–293.
Johnson MK, Hashtroudi S, and Lindsay DS (1993) Source monitoring. *Psychol. Bull.* 114: 3–28.
Johnson MK, De Leonardis DM, Hashtroudi S, and Ferguson SA (1995) Aging and single versus multiple cues in source monitoring. *Psychol. Aging* 10: 507–517.
Johnson RE (2003) Aging and the remembering of text. *Dev. Rev.* 23: 261–346.
Karpel ME, Hoyer WJ, and Toglia MP (2001) Accuracy and qualities of real and suggested memories: Nonspecific age differences. *J. Gerontol. Psychol. Sci.* 56B, P103–P110.
Kausler DH and Puckett JM (1980) Adult age differences in recognition memory for a nonsemantic attribute. *Exp. Aging Res.* 6: 349–355.
Laver GD and Burke DM (1993) Why do semantic priming effects increase in old age? A meta-analysis. *Psychol. Aging* 8: 34–43.
Li KZH (1999) Selection from working memory: On the relationship between processing and storage components. *Aging Neuropsychol. Cogn.* 6: 99–116.
Li KZH, Lindenberger U, Freund AM, and Baltes PB (2001) Walking while memorizing: Age-related differences in compensatory behavior. *Psychol. Sci.* 12: 230–237.
Light LL and Albertson SA (1988) Comprehension of pragmatic implications in young and older adults. In: Light LL and Burke DM (eds.) *Language, Memory and Aging*, pp. 133–153. New York: Cambridge University Press.
Light LL and Albertson SA (1989) Direct and indirect tests of memory for category exemplars in young and older adults. *Psychol. Aging* 4: 487–492.
Light LL and La Voie D (1993) Direct and indirect measures of memory in old age. In: Graf P and Masson MEJ (eds.) *Implicit Memory: New Directions in Cognition, Development, and Neuropsychology*, pp. 207–230. Hillsdale, NJ: Erlbaum.
Light LL and Singh A (1987) Implicit and explicit memory in young and older adults. *J. Exp. Psychol. Learn. Mem. Cogn.* 13: 531–541.
Light LL, Prull MW, La Voie DJ, and Healy MR (2000) Dual-process theories of memory in old age. In: Perfect TJ and Maylor EA (eds.) *Models of Cognitive Aging*, pp. 238–300. New York: Oxford University Press.
Light LL, Patterson MM, Chung C, and Healy MR (2004) Effects of repetition and response deadline on associative recognition in young and older adults. *Mem. Cogn.* 32: 1182–1193.
Loftus EF and Palmer JC (1974) Reconstruction of automobile destruction: An example of the interaction between language and memory. *J. Verb. Learn. Verb. Behav.* 13: 585–589.
Lövdén M, Rönnlund M, Wahlin A, Bäckman L, Nyberg L, and Nilsson L-G (2004) The extent of stability and change in episodic and semantic memory in old age: Demographic predictors of level and change. *J. Gerontol. Psychol. Sci.* 59B: P130–P134.
Madden DJ (1988) Adult age differences in the effects of sentence context and stimulus degradation during visual word recognition. *Psychol. Aging* 3: 167–172.
Mather M and Carstensen LL (2005) Aging and motivated cognition: The positivity effect in attention and memory. *Trends Cogn. Sci.* 9: 496–502.
May CP, Hasher L, and Stoltzfus ER (1993) Optimal time of day and the magnitude of differences in memory. *Psychol. Sci.* 4: 326–330.
May CP, Hasher L, and Foong N (2005) Implicit memory, age, and time of day: Paradoxical priming effects. *Psychol. Sci.* 16: 96–100.
Mayr U, Spieler DH, and Kliegl R (2001) *Ageing and Executive Control*. New York: Psychology Press.
Mikels JA, Larkin GR, Reuter-Lorenz PA, and Carstensen LL (2005) Divergent trajectories in the aging mind: Changes in working memory for affective versus visual information with age. *Psychol. Aging* 20: 542–553.
Mitchell KJ, Johnson MK, Raye CL, Mather M, and D'Esposito M (2000) Aging and reflective processes of working memory: Binding and test load deficits. *Psychol. Aging* 15: 527–541.
Naveh-Benjamin M (2000) Adult age differences in memory performance: Tests of an associative deficit hypothesis. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1170–1187.
Naveh-Benjamin M, Hussain Z, Guez J, and Bar-On M (2003) Adult age differences in episodic memory: Further support for an associative-deficit hypothesis. *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 826–837.
Naveh-Benjamin M, Guez J, Kilb A, and Reedy S (2004) The associative memory deficit of older adults: Further support using face-name associations. *Psychol. Aging* 19: 541–546.
Naveh-Benjamin M, Craik FIM, Guez J, and Kreuger S (2005) Divided attention in younger and older adults: Effects of strategy and relatedness on memory performance and secondary task costs. *J. Exp. Psychol. Learn. Mem. Cogn.* 31: 520–537.
Naveh-Benjamin M, Keshet Brav T, and Levy O (2007) The associative memory deficit of older adults: The role of strategy utilization. *Psychol. Aging* 22: 202–208.
Park DC, Hertzog C, Kidder DP, Morrell RW, and Mayhorn CB (1997) Effect of age on event-based and time-based prospective memory. *Psychol. Aging* 12: 314–327.
Park DC, Lautenschlager G, Hedden T, Davidson NS, Smith AD, and Smith PK (2002) Models of visuospatial and verbal memory across the adult life span. *Psychol. Aging* 17: 299–320.

Parkinson SR (1982) Performance deficits in short-term memory tasks: A comparison of amnesic Korsakoff patients and the aged. In: Cermak LS (ed.) *Human Memory and Amnesia*, pp. 77–96. Hillsdale, NJ: Erlbaum.
Prull MW, Dawes LLC, Martin III, AM, Rosenberg HF, and Light LL (2006) Recollection and familiarity in recognition memory: Adult age differences and neuropsychological test correlates. *Psychol. Aging* 21: 107–118.
Puckett JM and Lawson WM (1989) Absence of adult age differences in forgetting in the Brown-Peterson task. *Acta Psychol.* 72: 159–175.
Puglisi JT, Park DC, Smith AD, and Hill GW (1985) Memory for two types of spatial location: Effects of instructions, age, and format. *Am. J. Psychol.* 98: 101–118.
Rabinowitz JC, Craik FIM, and Ackerman BP (1982) A processing resource account of age differences in recall. *Can. J. Psychol.* 36: 325–344.
Rahhal TA, Hasher L, and Colcombe SJ (2001) Instructional manipulations and age differences in memory: Now you see them, now you don't. *Psychol. Aging* 16: 697–706.
Rendell PG and Craik FIM (2000) Virtual week and actual week: Age-related differences in prospective memory. *Appl. Cogn. Psychol.* 14: S43–S62.
Rendell PG, Castel AD, and Craik FIM (2005) Memory for proper names in old age: A disproportionate impairment? *Q. J. Exp. Psychol.* 58A: 54–71.
Roediger HL III (1990) Implicit memory: Retention without remembering. *Am. Psychol.* 45: 1043–1056.
Roediger HL III and Geraci L (2007) Aging and the misinformation effect: A neuropsychological analysis. *J. Exp. Psychol. Learn. Mem. Cogn.* 33: 321–334.
Roediger HL III and McDermott KB (1995) Creating false memories: Remembering words not presented in lists. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 803–814.
Rönnlund M, Nyberg L, Bäckman L, and Nilsson L-G (2005) Stability, growth, and decline in adult life span development of declarative memory: Cross-sectional and longitudinal data from a population-based study. *Psychol. Aging* 20: 3–18.
Salthouse TA (1988) Resource-reduction interpretations of cognitive aging. *Dev. Rev.* 8: 238–272.
Salthouse TA (1991a) Mediation of adult age differences in cognition by reductions in working memory and speed of processing. *Psychol. Sci.* 2: 179–183.
Salthouse TA (1991b) *Theoretical Perspectives on Cognitive Aging*. Hillsdale, NJ: Erlbaum.
Salthouse TA (1996) The processing-speed theory of adult age differences in cognition. *Psychol. Rev.* 103: 403–428.
Salthouse TA, Berish DE, and Miles JD (2002) The role of cognitive stimulation on the relations between age and cognitive functioning. *Psychol. Aging* 17: 548–557.
Salthouse TA, Siedlecki KL, and Krueger LE (2006) An individual differences analysis of memory control. *J. Mem. Lang.* 55: 102–125.
Schacter DL, Chiu C-YP, and Ochsner KN (1993) Implicit memory: A selective review. *Ann. Rev. Neurosci.* 16: 159–182.
Schaie KW (2000) The impact of longitudinal studies on understanding development from young adulthood to old age. *Int. J. Behav. Dev.* 24: 257–266.
Siedlecki KL, Salthouse TA, and Berish DE (2005) Is there anything special about the aging of source memory? *Psychol. Aging* 20: 19–32.
Spencer WD and Raz N (1995) Differential effects of aging on memory for content and context: A meta-analysis. *Psychol. Aging* 10: 527–539.
Squire LR (1986) Mechanisms of memory. *Science* 232: 1612–1619.
Stine-Morrow EAL, Gagne DD, Morrow DG, and DeWall BH (2004) Age differences in rereading. *Mem. Cogn.* 32: 696–710.
Troyer AK, Winocur G, Craik FIM, and Moscovitch M (1999) Source memory and divided attention: Reciprocal costs to primary and secondary tasks. *Neuropsychology* 13: 467–474.
Troyer AK, Häfliger A, Cadieux MJ, and Craik FIM (2006) Name and face learning in older adults: Effects of level of processing, self-generation, and intention to learn. *J. Gerontol. Psychol. Sci.* 61B: P67–P74.
Vecchi T and Cornoldi C (1999) Passive storage and active manipulation in visuo-spatial working memory: Further evidence from the study of age differences. *Eur. J. Cogn. Psychol.* 11: 391–406.
Verhaeghen P and Salthouse TA (1997) Meta-analyses of age-cognition relations in adulthood: Estimates of linear and nonlinear age effects and structural models. *Psychol. Bull.* 122: 231–249.
Verhaeghen P, Marcoen A, and Goossens L (1992) Improving memory performance in the aged through mnemonic training: A meta-analytic study. *Psychol. Aging* 7: 242–251.
Verhaeghen P, Marcoen A, and Goossens L (1993) Facts and fiction about memory aging: A quantitative integration of research findings. *J. Gerontol. Psychol. Sci.* 48: P157–P171.
Wechsler D (1997) *Wechsler Adult Intelligence Scale*, 3rd edn. San Antonio: The Psychological Corporation.
Welford AT (1980) Memory and age: A perspective view. In: Poon LW, Fozard JL, Cermak LS, Arenberg D, and Thompson LW (eds.) *New Directions in Memory and Aging: Proceedings of the George A. Talland Memorial Conference*, pp. 1–17. Hillsdale, NJ: Erlbaum.
West R, Murphy KJ, Armilio ML, Craik FIM, and Stuss DT (2002) Lapses of intention and performance variability reveal age-related increases in fluctuations of executive control. *Brain Cogn.* 49: 402–419.
Wetherell JL, Reynolds CA, Gatz M, and Pedersen NL (2002) Anxiety, cognitive performance, and cognitive decline in normal aging. *J. Gerontol. Psychol. Sci. Soc. Sci.* 57B: P246–P255.
Wingfield A, Lindfield KC, and Kahana MJ (1998) Adult age differences in the temporal characteristics of category free recall. *Psychol. Aging* 13: 256–266.
Yonelinas AP (2002) The nature of recollection and familiarity: A review of 30 years of research. *J. Mem. Lang.* 46: 441–517.
Yoon C, May CP, and Hasher L (1999) Aging, circadian arousal patterns, and cognition. In: Schwarz N, Park DC, Knäuper B, and Sudman S (eds.) *Cognition, Aging, and Self-Reports*, pp. 117–143. Philadelphia: Psychology Press.
Zacks RT and Hasher L (1997) Cognitive gerontology and attentional inhibition: A reply to Burke and McDowd. *J. Gerontol. Psychol. Sci.* 52B: P274–P283.

# 2.42 Superior Memory of Mnemonists and Experts in Various Domains

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## 2.42.1 Superior Memory of Mnemonists and Experts in Various Domains

One of the most striking individual differences between people concerns their ability to recall information and everyday events. Some people seem to remember an exceptional amount of details of past events – much more than others who also were present and thus presumably had a similar experience. It is difficult to validate any superior memory accounts because there are rarely objective records, such as video recordings. As a consequence, the recall of people with reputation for having a good memory is often simply accepted, even when other people cannot recall the same information. There are, however, bodies of cultural and professional knowledge, which are publicly accessible in the form of periodicals, books, and encyclopedias. Memory for this type of knowledge is measured regularly by schools, universities, and professional licensing boards. Based on such tests, we know that experts have a greater body of knowledge about their domain of expertise than other individuals. These tests also show substantial individual differences between experts who have the same educational background and thus similar opportunities to acquire the same knowledge. How is it possible to explain these large differences in memory and accumulated knowledge?

Ideas of individual differences in memory depend on one's general conception of the process of memory formation. Plato viewed the formation of memories as akin to the impressions made by a signet ring on a wax tablet (Yates, 1966). Due to differences in the hardness and quality of the wax, some people would be able to make sharp impressions (accurate memory), whereas others were diffuse and rough (poor memory). This account matches many people's introspective impressions that their memories are clear and vivid and sometimes even approach the vividness of the original experiences. Some people are even believed to possess the ability to store completely accurate visual images (photographic memory) (La Brecque, 1972). From this conception of individual differences in memory we would expect a superiority of memory that would generalize across all sorts of domains.

There are two types of evidence on superior memory. One type concerns the domain-specific superiority of experts to remember new information and experiences in their domain of expertise. Some elite athletes can, after a sports event, discuss the play-by-play action. Expert chess players can readily recall details of chess positions from their matches in recent tournaments. There are even numerous anecdotes that were collected as evidence of an unusual ability to store presented information rapidly in their domain of specialization. For example, Mozart was supposed to be able to reproduce a presented piece of music after hearing it a single time. Although these feats could be explained by a general superiority of memory, it is rarely supported by reliable evidence. Most experts' strikingly superior memory appears to be limited to information in their domain of expertise, with, if anything, poorer memory for other information and particularly more mundane material, such as information about people, appointments, and other everyday issues. This preoccupation with some domain does not preclude their having a generally superior memory when they attend to information with the intent to commit it to memory. Scientists realized that it is necessary to find experts who are willing to be tested to assess whether they have fundamentally different and generally superior memories. Their controlled memory studies have found that the memory advantage of experts was surprisingly specific to the domain of expertise, as will be described in more detail later in this entry.

The other type of evidence for superior memory is found when some individuals are able to memorize seemingly meaningless information, such as names of people, lists of digits and unrelated words, and verbatim text in an unfamiliar foreign language. Superior memory for this type of seemingly meaningless information was initially assumed to be mediated by some superior general capacity to store information in memory that would generalize to all types of materials. Laboratory studies testing the memory of people with this type of superior memory found that any time the performance was exceptional – outside the range of random sample of adults, then the performance was limited to a small number of types of material, such as digits, letters, and playing cards. Furthermore, these individuals were found to have engaged in extended memory training using various mnemonic memory strategies that allow seemingly meaningless information to be encoded with meaningful associates already in memory. For example, 9631492177 could be encoded as [1]963 (death of Kennedy) 1492 (Columbus) and 177[6] (American Revolution). In sum, recent research (Ericsson, 2003; Wilding and Valentine, 2006) has rejected the hypothesis of an exceptional innate memory capacity that generalizes across materials and has demonstrated that exceptionally superior memory is limited to some particular types of materials and domains of expertise and reflects the result of acquired skills and knowledge relevant to each specific domain.

## 2.42.2 Brief Historical Background

Sir Francis Galton (1883) innovated the method of interviewing many people by sending out a list of questions about mental imagery—said to be the first questionnaire. He was interested in how the memory and imagery of exceptional people, such as scientists, judges, and other famous people of his time, differed from regular people. He had been intrigued by reports of photographic memory and asked questions of the acuity of specific memories, such as the clarity and brightness of their memory for specific things such as their breakfast table. He found striking individual differences in the clarity or vividness, but no clear superiority of the eminent scientists: for example, Darwin reported having weak visual images. Now over a hundred years later, it is still unclear what these large individual differences in reported vividness of memory images reflect in objective performance, as will be discussed later in this section.

A few years later Ebbinghaus (1885/1964) published his seminal work on laboratory studies of memory, where he argued that individual differences in memory between adults in everyday life were primarily caused by differences between individuals' knowledge and prior experience. He consequently suggested that psychologists should present unfamiliar materials, such as nonsense syllables, under controlled conditions in the laboratory and then assess the number of repetitions necessary for successful reproduction. Ebbinghaus designed his studies so he could be a participant and based on the data from a single participant (himself) to uncover the general laws of human associative memory. All of his findings have been replicated thousands of times with large groups of naive participants (Slamecka, 1985a,b). One of the findings relevant to superior memory was that Ebbinghaus found that memory for nonsense syllables is much worse than memory for typical information encountered in everyday life – in fact, he needed ten times more time to memorize lists of nonsense syllables compared to the poems with the same number of syllables. Other contemporary psychologists, most notably Alfred Binet (1894), raised doubts about whether memory for nonsense syllables was mediated by the same types of processes as memory in everyday and exceptional memory by mental calculators and chess players.

Binet's (1893/1966) report on chess players' 'mnemonic virtuosity' was arguably the first published study on memory and expertise. Binet interviewed chess players about their ability to play chess blindfolded without seeing a chessboard. The ability required to maintain chess position in memory during blindfolded play did not appear to reflect a basic memory capacity to store complex visual images, but a deeper understanding of the structure of chess. Hence, to play chess blindfolded requires knowledge and skill to understand the reasoning that led to each chess move. It is the ability to discover the meaningful connections between these ideas that provides the basis for the superior memory and the ability to maintain a chess position in memory. However, Binet found that the verbal descriptions of the visual images of the mental chess positions differed enormously between blindfolded chess players. Some claimed to see the board as clearly as if it was shown perceptually with all the details and even shadows. Other chess players reported seeing no visual images during blindfolded play and claimed to rely on abstract characteristics of the chess position. Unfortunately, there was no independent evidence to support or question the validity of these diverse introspective reports. Binet (1893/1966) also studied mental calculators, who could multiply large numbers mentally, and other people with exceptional memory. He was able to show that memorization of a matrix of digits did not involve forming a visual image because subsequent retrieval was only rapid for retrieval of digits presented in the same row of the matrix (Ericsson and Chase, 1982).

Subsequent research was guided by the hypothesis that superior memory was mediated by innate talent and general basic capacities. In the early part of the twentieth century Djakow et al. (1927) measured the basic abilities of world-class chess players and compared their test performance to the average of a large sample of nonchess players. Contrary to the assumed importance of natural gifts, the international players were superior only on a single test – a test involving memory for chess positions. A few decades later de Groot (1946/1978) found that when chess players were instructed to select the best move for a briefly presented chess position, their ability to recall the positions of the chess pieces was closely related to chess skill. International chess masters were able to recall virtually all the pieces on the chessboard, whereas beginners could recall only a few pieces. Taken together, these two findings suggest that exceptional memory of chess masters is constrained to superior memory of meaningful chess positions – a claim that has been validated by subsequent research in the laboratory.

In parallel with the studies of chess experts' exceptional memory, several researchers conducted case studies of individuals with exceptional memory (for reviews, see Wilding and Valentine, 1997, 2006). The most influential series of studies was conducted by Luria (1968) on a newspaper reporter referred to as Subject S – an abbreviation for the last name of the participant, namely, Shereshevski. Luria (1968) found that S could memorize a wide range of materials, such as list of nonsense syllables and poetry in a foreign language, by forming eidetic images of meaningful associations. For example, to memorize the first few words in the first line of Dante's *The Divine Comedy*, namely, "Nel mezzo del cammin di nostre vita," S reported that he associated **Nel** by thinking, "I was paying my membership dues when there in the corridor, I caught sight of the ballerina **Nel**'skaya" (Luria, 1968: 47), and then associating mezzo with an image in the same context and then associating **del** by thinking, "There is a pack of **Del**i cigarettes near them' and so on" (Luria, 1968: 47). Although Luria attributed S's exceptional memory to the vividness of his eidetic memory, subsequent researchers argue that S was using a variant of the ancient method of loci (Yates, 1966), where presented information, such as a text in a foreign language, is recoded into meaningful images (see preceding example), which in turn are associated to familiar locations, such as the concert hall and adjacent streets and buildings. Skilled memory experts (mnemonists) who use the method of loci have acquired long lists of journeys of locations, such as locations encountered with visiting one's own house – the mailbox, driveway, garage door, garage, door at main entrance, and so on. Most importantly, Luria (1968) found that S was able to recall matrices of digits without the need to retrieve meaningful associations and was able to commit a matrix of 50 digits to memory in only 3 min. Later, S was able to recall the digits in an arbitrary manner, in columns and zigzag patterns, which led Luria (1968) to infer that digits were directly available as a visual image. Other studies of exceptional individuals, such as the mathematics professor Rückle (Müller, 1911) and the Japanese mnemonist Isihara (Susukita, 1933), showed similar findings and found that mnemonic encoding methods played a central role in their superior performance. Scientists also examined the memories of individuals who were able to make mathematical calculations mentally (mental calculators), such as the Polish mental calculator Dr. Finkelstein (Bousfield and Barry, 1933) and the mathematics professor Aiken (Hunter, 1962, 1977), and were able to establish both calculation methods and exceptional memory performances for numbers.

These case studies of exceptional memory relied extensively on the individuals' introspective descriptions of their experiences during interviews and the characteristics of their images and, in particular, their vividness. Other contemporary researchers studied children with eidetic imagery. These children reported having detailed visual images of presented complex stimuli even after they had been removed from view. Many researchers, including Luria (1968), argued that individuals with exceptional memory must be relying on a similar basic capacity to form and maintain visual images. After decades of research on describing the reports of eidetic imagery, researchers started measuring the memory performance of eidetic and normal children. To everyone's surprise there was no difference in memory performance between children who reported seeing an image of the presented stimuli and other children (Haber, 1979). More recently, researchers have studied ratings of the reported vividness of memory for an experience and the level of accurate recall of presented pictures (Richardson, 1988; McKelvie, 1995). Most surprisingly, the amount of recall was not found to differ between people who rated their memory image as very vivid (almost as clear as still seeing the picture) and people who reported having little visual image of the stimulus at all. These findings supported the opinions of many experimental psychologists, who held that introspective judgments about experience were frequently misleading and sometimes even inconsistent with measures of performance.

A scientific analysis of exceptional memory would need to be based on reliably superior performance that could be repeatedly reproduced in the laboratory. Similarly, introspective descriptions by individuals are not acceptable as valid data and should be discarded in favor of concurrent verbal reports of participants' thinking (Ericsson and Simon, 1993). These reports can be analyzed and explained as are other types of data on cognitive processes (e.g., eye fixations, latencies, and recordings of brain activity).

The following sections of this chapter will discuss experimental studies of exceptional memory performance that assess its scope and structure, the development of exceptional memory ability, the structure of superior memory of domain experts, and some recent developments in study of the pattern of brain activation during exceptional memory performance.

## 2.42.3 Experimental Studies of Exceptional Memory: Generalizability and Mediating Mechanisms

When somebody demonstrates exceptional memory for a list of digits or a chess position, it is only natural that one would expect that superior memory would generalize to any aspect of memory. It is not possible to assess the generalizability of the exceptional memory simply by observing the individuals' behavior involved in committing particular types of information of the person's own choosing under everyday life conditions. It is necessary to get their consent to participate in experiments where possible to vary the presented types of materials and conditions of memory. Some of the early investigations of exceptional memory showed that the formation of memory was not instantaneous, and although much faster than required by regular adults, it took considerable time. Even more important, exceptional memory is primarily demonstrated for seemingly meaningless or arbitrary types of materials, such as list of digits, nonsense syllables, and texts in a foreign language. In fact, some of the early laboratory studies showed that the dramatically superior memory performance was often limited to lists of a certain types of materials, such as lists of digits and words. For example, the Japanese memory expert Isahara did not show exceptional memory for presented color patches (Susukita and Heindl, 1935). In his review of mental calculators, Smith (1983) found that their superior memory was invariably limited to numbers and digits. The most influential study demonstrating the domain-specific nature of mechanisms involved in exceptional memory was conducted by Bill Chase and Herb Simon (Chase and Simon, 1973) on chess players' memory for chess configurations in the 1970s.

## 2.42.4 The Role of Meaningful Associations in Superior Memory Performance

In their pioneering studies Chase and Simon (1973) replicated the superior memory for chess positions by chess experts found previously by Djakow et al. (1927) and de Groot (1946/1978). Chess players ranging from a beginner to an international master were shown a position from an actual chess game (such as the one illustrated in **Figure 1(a)**) for a brief time (normally 5 s) and then asked to recall the locations of all the chess pieces. The ability to recall increased as a function of chess skill. Beginners at chess were able to recall the correct location of about four pieces, whereas international-level players recalled virtually all of the more than 20 pieces.

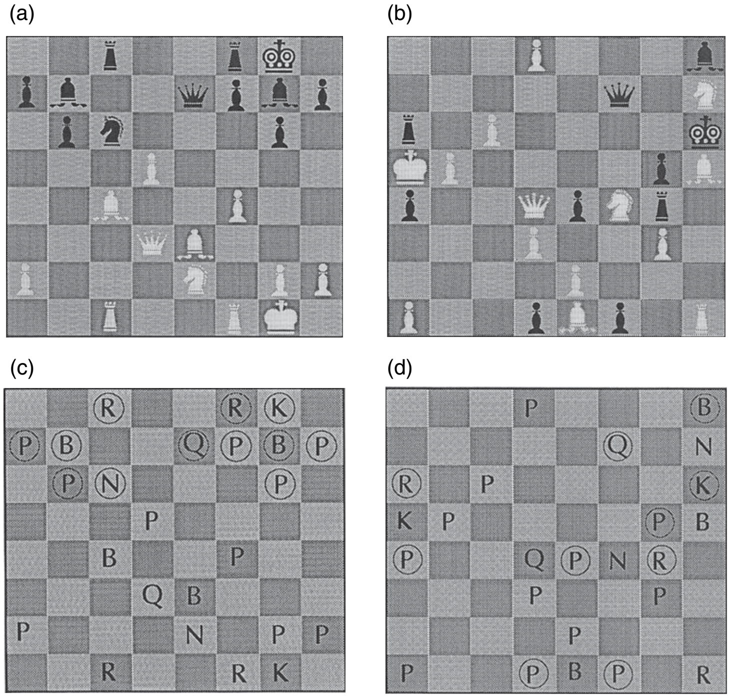


**Figure 1** Standard diagrams of an actual chess position (a) and a chessboard with randomly arranged pieces (b). Nonstandard representations of the same information using the first letter of the names of pieces are shown in (c) and (d).

To rule out that the superior memory of chess experts reflects a general superior ability to store any kind of visual information, Chase and Simon (1973) had chess players recall chessboards with randomly placed pieces (as illustrated in **Figure 1(b)**). With briefly presented random chessboards, players at all levels of skill had a similar poor recall performance and were able to recall the correct location of only about four pieces – a performance comparable with that of chess beginners for actual positions from chess games. Further, Chase and Simon (1973) showed that when an actual chess position was shown using an unfamiliar notation (see **Figure 1(c)** for an encoding of the meaningful positions and **Figure 1(d)** for the random positions), the chess expert was able to display a similar level of superior memory performance after a brief period of adjustment. These results imply that the superior memory of chess experts is not photographic and depends on seeing arrangements of chess pieces that can be encoded using associations to the experts' extensive knowledge of chess. Since Chase and Simon's classic study, investigators have replicated these findings for chess and found a slight yet reliable advantage of chess experts to recall more chess pieces even from random chess configurations (Gobet and Charness, 2006). Numerous other studies have also shown that level of expertise is related to superior memory performance for representative stimuli in the associated domain, such as computer programming, basketball, and dance, and that this superiority is mediated by increased knowledge and domain-specific skills (for a review, see Ericsson et al., 2000).

Unless one has the knowledge of the expert, it is difficult – indeed, impossible – to grasp the meaningful relations between chess pieces perceived by the expert in **Figure 1**(a) and **1(c)**. If, on the other hand, the availability of knowledge providing meaning to a stimulus is critical to superior memory, it should be possible to demonstrate the same effect in a domain where all adults are proficient, such as language. Human adults are able to recall verbatim meaningful sentences of 20 or more words after a brief presentation (Chase and Ericsson, 1982). An example of such a sentence would be: The woman in front of him was eating peanuts that smelled so good that he could barely contain his hunger. If the words of the sentence are randomly rearranged (analogous to Chase and Simon's procedure for generating random chessboards), accurate verbatim recall drops to around six words. An example of a random rearrangement of the preceding sentence would be: Was smelled front that his the peanuts he good hunger eating barely woman of so in could that him contain. For random lists of words, the recall of subjects is limited by the small number of words they can keep rehearsing, and once they stop rehearsal, the words are quickly forgotten. In contrast, once meaningful sentences are understood, their meaning is well retained in long-term memory. For example, during normal comprehension of a text the essential information in each sentence is efficiently stored in memory so it can be integrated with related information presented later in the text (Ericsson and Kintsch, 1995).

Stimuli from an unfamiliar domain of expertise, such as diagrams of chess positions and medical diagnoses, are often about as meaningless to most adults as random lists of words and digits. Studies described how people with exceptional memory for meaningless information actively sought out meaningful associations for the meaningless material, such as Subject S's encoding of the words of the Italian poem and remembering digits by noticing familiar dates, like 1945 – the year of the end of World War II. Individuals exhibiting truly exceptional memory performance for numbers, names, and pictures have been found to rely on some kind of mnemonics, relying on associations with previous knowledge, patterns, and acquired cognitive structures (Wilding and Valentine, 1997, 2006). There was always a question of whether individuals with exceptional memory were innately different and special or whether ordinary adults would be able to acquire exceptional memory through training.

## 2.42.5 Acquisition of Exceptional Memory through Practice and Training

The first study to trace the development of exceptional memory from average performance to the best memory performance in the world (in some memory tasks) was conducted in a training study by Chase and Ericsson (1981, 1982; Ericsson et al., 1980). We studied a college student (SF), whose initial immediate memory for rapidly presented digits was around 7, in correspondence with the typical average (Miller, 1956), but he eventually acquired exceptional performance for immediate memory and after 200 hours of practice was able to recall over 80 digits in the digit-span task. During this extended training period, we monitored any changes in SF's cognitive processes by having him give retrospective reports on his thought processes after most memory trials (this methodology is qualitatively different from the accounts given in interviews reported in the introduction of this article (cf. Ericsson and Simon, 1993). As his memory performance started to increase, he reported segmenting the presented lists into three-digit groups and whenever possible encoded them as running times for various races, because SF was an avid cross-country runner. For example, SF would encode 358 as a very fast mile time, 3 min and 58 s, just below the 4-min mile. The central question concerning any type of verbal reports is whether we can trust the validity of these reports and whether the ability to generate mnemonic running-time encodings influences memory.

To address that issue, we designed an experiment to test the effects of mnemonic encodings and presented SF with special types of lists of constrained digits. In addition to the list of random digits, we presented other lists that were constructed to contain only three-digit groups that could not be encoded as running times, such as 364 as 3 min and 64 s, in a list (364 895 481...). As predicted, his performance decreased reliably. In another experiment, we designed digit sequences where all three-digit groups could be encoded as running times (412 637 524 ...) with a reliable increase in his associated performance. In over a dozen specially designed experiments, it was possible to validate several aspects of SF's acquired memory skill (Chase and Ericsson, 1981, 1982; Ericsson, 1985). A similar methodology was applied to two other college students, who both attained exceptional memory after 50–200 h of training. In fact, one of the participants reached a digit span of over 100 digits (Richman et al., 1995). Other investigators, such as Wenger and Payne (1995), have also relied on protocol analysis and other process tracing data to assess the mechanisms of individuals who increased their memory performance dramatically with practice on a list learning task.

More generally, this method has been extended to any individual with exceptional memory performance. During the first step, the exceptional individuals are given memory tasks where they could exhibit their exceptional performance while giving concurrent and/or retrospective verbal reports. These reports are then analyzed to identify the mediating encoding and retrieval mechanisms of each exceptional individual. The validity of these accounts is then evaluated experimentally by presenting each individual with specially designed memory tasks that would predictably reduce that individuals' memory performance in a decisive manner (Ericsson, 1985; Wilding and Valentine, 1997). With this methodology, verbal reported mechanisms of superior performance have been validated with designed experiments in a wide range of domains, such as a waiter's superior memory for dinner orders (Ericsson and Polson, 1988), mental calculators (Chase and Ericsson, 1982), and other individuals with exceptional memory performance (Ericsson et al., 2004; Thompson et al., 1993). Several studies even demonstrated impressive memory improvements in large samples of participants after extended practice with instructions to use mnemonic encodings (Kliegl et al., 1987; Kliegl et al., 1989; Higbee, 1997).

## 2.42.6 Superior Memory of Experts and Their Superior Performance on Representative Tasks

Memory experts have been found to improve their memory performance by acquiring mnemonic techniques through extended practice. In contrast, chess experts and medical doctors attain superior memory for representative stimuli from the domain without training their memory deliberately. The primary goal for all experts is to excel at the representative tasks in their particular domain of expertise. For example, chess experts need to find the best moves to win chess matches, and medical experts have to diagnose sick patients to give them the best treatment. Their superior memory ability must thus be an indirect consequence of their improved performance on representative tasks (Vicente and Wang, 1998). Furthermore, experts appear to store task-relevant information in memory when they normally perform representative tasks in their domain, because if they are unexpectedly asked to recall information about a performed task, their memory is typically much superior to that of less-skilled individuals. In fact, experts' incidental memory of the relevant information is frequently so good that instructing them to intentionally memorize the information does not reliably improve their memory. For example, when chess experts analyze a position to find the best move, their memory of the position is just as good whether they were informed about an upcoming memory test or not. As part of performing the representative task of selecting the best move, the experts encode the important features of the presented information and store them in accessible form in memory. In contrast, when subjects, after training based on mnemonics and knowledge unrelated to chess, attain a recall performance comparable with that of the chess experts, they still lack the ability to extract the information important for selecting the best move. Hence, the remarkable characteristic of expert memory is not just the amount recalled, which can often be matched by training, but the rapid extraction and storage of important patterns and relevant information that allows the experts to perform better the representative task, such as selecting moves in chess (Ericsson, 2006a,b).

An analysis of expert performance shows that it is not sufficient to have merely stored the knowledge in memory; it is also critical that relevant knowledge is well organized and can be efficiently retrieved when it is relevant to the ongoing processes. In fact, the principal challenge of expertise is to acquire and organize the vast body of domain knowledge (Chi et al., 1981; Chi, 2006) such that all relevant prior knowledge can be immediately accessed to guide action in encountered situations. For example, with the superior organization of knowledge, a chess expert can rapidly perceive a promising move, or a medical expert can rapidly notice an inconsistency in a suggested diagnosis.

Efficient and reliable storage of relevant information in memory is especially important to experts when they engage in planning and complex reasoning that mediate their superior performance. During planning, experts have to mentally compare many alternative sequences of actions, which produces a great deal of information in working memory. Consequently, beginning chess players do not generate long plans, and it takes years of chess study before chess experts are able to plan long sequences of future moves reliably (Charness, 1989; Gobet and Charness, 2006). Chess masters eventually improve their memory skills for planning so much that they are even able to play chess without seeing the chessboard (blindfold chess), thus having to represent the locations of all the pieces on the board during the entire game in their mind. Analyses of the superior ability to plan suggest that experts acquire memory skills, which allow them to rely on long-term memory for storage of generated information (Ericsson and Kintsch, 1995). Recent research on expertise is making it increasingly clear that the vast knowledge of experts has to be well organized and supplemented with special memory skills so as to support memory-demanding planning, design, and reasoning.

Recent research has revealed the complex and intricate structure of expert performance and its associated memory skills. These skills are not attained automatically with experience but require the engagement in deliberate practice, typically designed by teachers. Even the most talented individuals have spent around 10 years of intense preparation before attaining an international level of performance in many domains, such as sports, chess, and arts (Ericsson, 2006b).

## 2.42.7 Research on Brain Structure and Activation Associated with Superior Memory Performance

Do the brains of people with exceptional memory differ in their anatomical features or their pattern of activation while exhibiting their superior memory performance? It is difficult to determine whether the brain of a single individual with exceptional memory differs from those of other people with similar gender, age, education, and ethnic background. Differences in the anatomical structure of brains exhibiting exceptional memory compared to a control sample have been found for taxi drivers in London, who have spent several years before they have successfully memorized the map of London with its massive number of streets, hotels, and significant landmarks (Maguire et al., 2003a). Most interestingly, the differences in the taxi drivers' hippocampus appear to be a consequence of the extended initial memorization of the London map as well as the daily work as a cab driver, rather than any innate differences.

More recently, Maguire et al. (2003b) examined the brains of ten of the world's foremost memory performers and compared them to control subjects with matched spatial ability and intelligence. They found no systematic anatomical differences between the two groups. This study also recorded the brain activity (functional magnetic resonance imaging) of both groups of participants while they were engaged in memorizing different types of stimuli for which the memory expert either exhibited clearly superior memory, namely three-digit numbers; intermediate superiority, namely faces; or no superior memory, namely snow crystals. After completing the memory tests, the participants gave detailed descriptions of their encoding strategies during the memorization. All of the memory performers reported using previously acquired techniques for generating associations, such as mnemonics, to make the presented information more memorable. All but one of the memory performers reported using the method of loci. In sharp contrast, none of the control group reported using any of the standard mnemonic techniques. These reported differences in strategies were sufficient to explain the regional differences in brain activation observed during memorization.

Recent brain-imaging studies of exceptional performers show that they activate brain regions that are different from those activated by control subjects. Consistent with accounts of memory experts, their differential brain activation is consistent with cognitive processes reflecting acquired memory skill. For example, exceptional mental calculators rely on storage in long-term memory (Presenti et al., 2001), and expert mental abacus calculators encode numbers in a manner qualitatively different from that of controls (Tanaka et al., 2002).

## 2.42.8 Conclusion and Future Directions

The emerging research on exceptional memory does not support the traditional views that only some uniquely gifted individuals endowed with an innately different memory system can attain exceptionally superior memory performance for particular types of information. Instead, the accumulated evidence supports the plasticity of the memory system in response to practice. The evidence supports the potential for ordinary healthy individuals to improve their memory performance with appropriate strategies and practice. However, future research is required to understand the specific processes of physiological adaptation of the brain and detailed modification of skills that occurs during extended skill acquisition. This research will need to combine cognitive and brain-imaging methods to study the process of skill acquisition and the changes required to reach exceptional levels of memory performance.

## References

Binet A (1894) *Psychologie des grands calculateurs et joueurs d'echecs* [The psychology of great calculators and chess players]. Paris: Libraire Hachette.

Binet A (1893/1966) Mnemonic virtuosity: A study of chess players, Simmel ML and Barron SB (trans.). *Genet. Psychol. Mono.* 74: 127–162.

Bousfield WA and Barry H (1933) The visual imagery of a lightning calculator. *Am. J. Psychol.* 45: 353–358.

Charness N (1989) Expertise in chess and bridge. In: Klahr D and Kotovsky K (eds.) *Complex Information Processing: The Impact of Herbert A. Simon*, pp. 183–208. Hillsdale NJ: Erlbaum.

Chase WG and Ericsson KA (1981) Skilled memory. In: Anderson JR (ed.) *Cognitive Skills and Their Acquisition*, pp. 141–189. Hillsdale, NJ: Erlbaum.
Chase WG and Ericsson KA (1982) Skill and working memory. In: Bower GH (ed.) *The Psychology of Learning and MotIvation,* Vol. 16, pp. 1–58. New York: Academic Press.
Chase WG and Simon HA (1973) The mind's eye in chess. In: Chase WG (ed.) *Visual Information Processing*, pp. 215–281. New York: Academic Press.
Chi MTH (2006) Two approaches to the study of experts' characteristics. In: Ericsson KA, Charness N, Feltovich P, and Hoffman RR (eds.) *Cambridge Handbook of Expertise and Expert Performance*, pp. 21–30. Cambridge, UK: Cambridge University Press.
Chi MTH, Feltovich PJ, and Glaser R (1981) Categorization and representation of physics problems by experts and novices. *Cogn. Sci.* 5: 121–152.
de Groot A (1946/1978) *Thought and Choice in Chess*. The Hague: Mouton.
Djakow JN, Petrowski NW, and Rudik PA (1927) *Psychologie des Schachspiels* [The psychology of chess]. Berlin: Walter de Gruyter.
Ebbinghaus H (1885/1964) *Memory: A Contribution to Experimental Cognitive Psychology,* Ruger HA and Bussenius CE (trans.). New York: Dover.
Ericsson KA (1985) Memory skill. *Can. J. Psychol.* 39: 188–231.
Ericsson KA (2003) Exceptional memorizers: Made, not born. *Trends Cogn. Sci.* 7: 233–235.
Ericsson KA (2006a) Protocol analysis and expert thought: Concurrent verbalizations of thinking during experts' performance on representative task. In: Ericsson KA, Charness N, Feltovich P, and Hoffman RR (eds.) *Cambridge Handbook of Expertise and Expert Performance*, pp. 223–242. Cambridge, UK: Cambridge University Press.
Ericsson KA (2006b) The influence of experience and deliberate practice on the development of superior expert performance. In: Ericsson KA, Charness N, Feltovich P, and Hoffman RR (eds.) *Cambridge Handbook of Expertise and Expert Performance*, pp. 685–706. Cambridge, UK: Cambridge University Press.
Ericsson KA and Chase WG (1982) Exceptional memory. *Am. Sci.* 70: 607–615.
Ericsson KA, Chase WG, and Faloon S (1980) Acquisition of a memory skill. *Science* 208: 1181–1182.
Ericsson KA, Delaney PF, Weaver G, and Mahadevan R (2004) Uncovering the structure of a memorist's superior 'basic' memory capacity. *Cogn. Psychol.* 49: 191–237.
Ericsson KA and Kintsch W (1995) Long-term working memory. *Psychol. Rev.* 102: 211–245.
Ericsson KA, Patel VL, and Kintsch W (2000) How experts' adaptations to representative task demands account for the expertise effect in memory recall: Comment on Vicente and Wang (1998). *Psychol. Rev.* 107: 578–592.
Ericsson KA and Polson PG (1988) An experimental analysis of the mechanisms of a memory skill. *J. Exp. Psychol. Learn. Mem. Cogn.* 14: 305–316.
Ericsson KA and Simon HA (1993) *Protocol Analysis; Verbal Reports as Data,* rev. edn. Cambridge, MA: Bradford Books/ MIT Press.
Galton F and Sir (1883) *Inquiries into Human Faculty and Its Development*. London: Macmillan.
Gobet F and Charness N (2006) Expertise in chess. In: Ericsson KA, Charness N, Feltovich P, and Hoffman RR (eds.) *Cambridge Handbook of Expertise and Expert Performance*, pp. 523–538. Cambridge, UK: Cambridge University Press.
Haber RN (1979) Twenty years of haunting eidetic imagery: Where's the ghost? *Behav. Brain Sci.* 2: 583–629.
Higbee KL (1997) Novices, apprentices, and mnemonists: Acquiring expertise with the phonetic mnemonic. *Appl. Cogn. Psychol.* 11: 147–161.
Hunter IML (1962) An exceptional talent for calculative thinking. *Br. J. Psychol.* 53: 243–258.
Hunter IML (1977) An exceptional memory. *Br. J. Psychol.* 68: 155–164.
Kliegl R, Smith J, and Baltes PB (1989) Testing-the-limits and the study of adult age differences in cognitive plasticity of a mnemonic skill. *Dev. Psychol.* 25: 247–256.
Kliegl R, Smith J, Heckhausen J, and Baltes PB (1987) Mnemonic training for the acquisition of skilled digit memory. *Cogn. Instruction* 4: 203–223.
La Brecque M (1972) Photographic memory. *Leonardo* 5: 347–349.
Luria AR (1968) *The Mind of a Mnemonist*. New York: Avon.
Maguire EA, Spiers HJ, Good CD, Hartley T, Frackowiak RS, and Burgess N (2003) Navigation expertise and the human hippocampus: A structural brain imaging analysis. *Hippocampus* 13: 250–259.
Maguire EA, Valentine ER, Wilding JM, and Kapur N (2003) Routes to remembering: The brains behind superior memory. *Nat. Neurosci.* 6: 90–95.
McKelvie SJ (1995) The VVIQ and beyond: Vividness and its measurement. *J. Ment. Imag.* 19: pp197–252.
Miller GA (1956) The magical number seven, plus or minus two: Some limits of our capacity for processing information. *Psychol. Rev.* 63: 81–97.
Müller GE (1911) Zur Analyse der Gedächtnistätigkeit und des Vorstellungsverlaufes: Teil I [Toward analyses of memory and imagery: Part I]. *Z. Psychol.* 5(supplement): 1–403.
Presenti M, Zago L, Crivello F, et al. (2001) Mental calculation in a prodigy is sustained by right prefrontal and medial temporal areas. *Nat. Neurosci.* 4: 103–107.
Richman HB, Staszewski JJ, and Simon HA (1995) Simulation of expert memory using EPAM IV. *Psychol. Rev.* 102: 305–330.
Richardson JTE (1988) Vividness and unvividness: Reliability, consistency, and validity of subjective imagery ratings. *J. Ment. Imag.* 12: 115–122.
Slamecka NJ (1985a) Ebbinghaus: Some associations. *J. Exp. Psychol. Learn. Mem. Cogn.* 11: 414–435.
Slamecka NJ (1985b) Ebbinghaus: Some rejoinders. *J. Exp. Psychol. Learn. Mem. Cogn.* 11: 496–500.
Smith SB (1983) *The Great Mental Calculators*. New York: Columbia University Press.
Susukita T (1933) Untersuchung eines ausserordentlichen Gedächtnisses in Japan (I) [A study of an exceptional memory in Japan (I)]. *Tohoku Psychol. Folia* 1: 111–154.
Susukita T and Heindl R (1935) Der Gedächtniskünstler als Zeuge [Memory experts as eyewitnesses]. *Arch. Kriminologie* 97: 93–99.
Tanaka S, Michimata C, Kaminaga T, Honda M, and Sadato N (2002) Superior digit memory of abacus experts: An event-related functional MRI study. *Neuroreport* 13: 2187–2191.
Thompson CP, Cowan TM, and Frieman J (1993) *Memory Search by a Memorist*. Hillsdale, NJ: Erlbaum.
Vicente KJ and Wang JH (1998) An ecological theory of expertise effects in memory recall. *Psychol. Rev.* 105: 33–57.
Wenger MJ and Payne DG (1995) On the acquisition of mnemonic skill: Application of skilled memory theory. *J. Exp. Psychol. App.* 1: 194–215.
Wilding J and Valentine E (1997) *Superior Memory*. Hove, UK: Psychology Press.
Wilding J and Valentine E (2006) Exceptional memory. In: Ericsson KA, Charness N, Feltovich P, and Hoffman RR (eds.) *Cambridge Handbook of Expertise and Expert Performance*, pp. 539–552. Cambridge, UK: Cambridge University Press.
Yates FA (1966) *The Art of Memory*. Chicago: University of Chicago Press.

# 2.44 Eyewitness Identification

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In the course of a criminal trial, eyewitness testimony can be very persuasive evidence (e.g., Wells et al., 1981; Fox and Walters, 1986; Cutler et al., 1990). Although the law makes no distinction between the relative weights juries should give to various types of evidence (United States v. Ramirez-Rodriguez, 1977), eyewitness evidence is most influential and salient to jurors even when paired with direct evidence that is inconsistent with the eyewitness identification (Fox and Walters, 1986; Cutler et al., 1990). Eyewitness identification of crime perpetrators is a common form of eyewitness testimony, forming the primary and sometimes the sole evidence in criminal cases. Eyewitness identification, however, is frequently inaccurate (Rattner, 1988; Wells, 1993; Wells and Bradfield, 1999; Wells et al., 1998).

Two independent phenomena combined in the late 1990s to create a perfect storm which resulted in a movement to reform the procedures by which eyewitness identifications are typically obtained, the lineup. First, research on eyewitness identification grew and matured throughout the 1980s and 1990s. By the late 1990s, effects of lineup instructions, filler selection, lineup presentation, and confidence assessment were fairly well understood based on a substantial body of research. Second, technical advances in DNA testing of identity and solid investigative work by the Innocence Project led to the growing realization that many innocent people had been convicted of serious felonies and had spent years in prison (Sheck et al., 2000). For example, the Innocence Project (groups of attorneys and law students operating out of law schools and legal clinics) has to date identified 200 cases of erroneous conviction. Mistaken identification is cited as the single leading cause of these erroneous convictions (Cutler and Penrod, 1995). Many of these erroneous conviction cases involve vivid, dramatic accounts of convicted felons who steadfastly maintained their innocence and traumatized and sincere eyewitnesses who with equal vehemence stood by their identifications (e.g., Junkin and Bloodsworth, 2004; Transcript of Penny Beernsten's speech, 2006; Transcript of Jennifer

Thompson Cannino's speech, 2006). Because eyewitness testimony is so prevalent and because such testimony can have dire consequences for the defendant, it has inspired volumes of research.

Given the voluminous research on eyewitness identification, an exhaustive review is untenable, even as a handbook chapter. Instead, we have adopted the following, more achievable objectives for this chapter. First, we provide an overview of the breadth of research on eyewitness memory. Second, we select two subsets of this research for more in-depth review: Estimator and system variables affecting eyewitness identification. Within each subset we review a sample of specific factors that have well-established effects on identification accuracy. For each of these variables, we provide a description of the effect on eyewitness identification accuracy and review a sample experiment to illustrate the science behind the research conclusions. We then summarize the state of knowledge regarding the factor, usually based on a published meta-analysis. We describe existing theory or at least speculation concerning the causes of the underlying effects of the factor. Following each subset of variables we discuss the practical implications of the knowledge gleaned from the research and how this knowledge influences actual policy and practices within the criminal justice system.

As mentioned, we divide this chapter into two subsets, estimator and system variables, a dichotomy that was developed nearly 30 years ago by Gary Wells (1978) and that continues to serve as a useful and oft-cited guiding principle today. Estimator variables are variables over which the police and criminal justice system exert no control. Many of these variables are those associated with the encoding stage of memory, such as the length of time the culprit is in view, whether the culprit wears a disguise or covers his face, whether the culprit has a gun, and the amount of stress experienced by the witness. They are called estimator variables because their main utility is to be used to estimate the reliability of an eyewitness's identification. System variables, by contrast, are under the control of the judicial system. These variables can therefore be used to enhance the likelihood of correct identification or minimize the likelihood of false identification. Examples of system variables include the instructions given to the eyewitness prior to a lineup, the selection of fillers for the lineup, and the manner in which the lineup is presented to the eyewitness. Research on estimator and system variables contributes to our understanding of the myriad of factors influencing identification accuracy, and both sets of variables have led to practical applications.

## 2.44.1 Breadth of Research on Eyewitness Memory

In addition to the distinction between estimator and system (independent) variables, the research on eyewitness identification can also be divided into two general categories, identifiable by the primary dependent variables: eyewitness recall and eyewitness identification. The estimator-system variable distinction applies to both categories of dependent variables. With respect to eyewitness recall, examples of estimator variable research programs include the impact of misleading postevent information on eyewitness memory, the suggestibility of child witnesses, the conditions under which people form false memories, and factors affecting peoples' abilities to describe perpetrators and crimes. System variable research on eyewitness recall has focused on such issues as the development of interview practices that increase the amount of accurate information recalled by eyewitnesses (e.g., the cognitive interview), and interviewing techniques for minimizing errors in children's recall.

A list of estimator and system variables examined in eyewitness recall and identification is presented in **Table 1** (column 1), followed by the percentage of experts in the field that agree that phenomenon is reliable (column 2), descriptions of their general effects (column 3), citations to sample studies (column 4), and citations to review papers – meta-analyses if available (column 5). As one can see, the number and range of variables examined are substantial. Column 2 of **Table 1** is an interesting index and requires some explanation. Kassin and colleagues (2001) authored an article describing a study of the general acceptance of factors affecting eyewitness identification. Kassin et al. surveyed 64 eyewitness researchers (mainly cognitive and social psychologists who had authored published research on eyewitness memory) for their opinions about the extent to which the factors listed (and some not listed) are reliable enough to testify about in court. The primary purpose of this study was to empirically address a concern that frequently arises in courts when expert witnesses are proffered. Our purpose in including this information is to provide another

**Table 1** List of system and estimator variables with representative and review studies

| *Variables* | *Expert agreement*[a] | *Major results* | *Representative study* | *Review study* |
|---|---|---|---|---|
| Weapon focus | 87% | Reduced ID and description accuracy when weapon is present | Loftus et al., 1987 | Steblay, 1992 |
| Disguise | | Reduced ID accuracy with disguises and physical transformations | Cutler et al., 1987a, b | Cutler, 2006 |
| Stress | 60% | Extreme stress impairs ID accuracy | Morgan et al., 2004 | Deffenbacher et al., 2004 |
| Own-race bias | | Reduced ID with other-race than same-race identifications | Platz and Hosch, 1988 | Meissner and Brigham, 2001a |
| Exposure time | 81% | Longer viewing times increase identification accuracy | Valentine et al., 2003 | Shapiro and Penrod, 1986 |
| Speed of identification | 40% | Faster identifications lead to more accurate identifications | Sporer et al., 1993 | Weber et al., 2004 |
| Unconscious transference | 81% | False identification of person who seems familiar because he/she was encountered near scene of crime | Read et al., 1990a | Ross et al., 1990 |
| Misleading postevent information | 94% | Reduces witness accuracy | Loftus et al., 1978 | Loftus, 1996 |
| Retention interval | 83% | Longer retention intervals (>1 week) lead to less accurate identifications | Shepherd, 1983 | Shapiro and Penrod, 1986 |
| Confidence malleability | 95% | Witness confidence is affected by social factors unrelated to accuracy | Bradfield and Wells, 2000 | Leippe, 2006 |
| Confidence accuracy | 87% | Relationship strong only when choosers are considered | Cutler et al., 1987a | Sporer et al., 1995 |
| Alcohol intoxication | 90% | Alcohol impairs witness identification | Morgan et al., 2004 | Birnbaum and Parker, 1977 |
| Hypnotic suggestibility | 91% | Increases false reports | Karlin and Orne, 1996 | Lynn et al., 1997 |
| Hypnotic accuracy | 45% | Small increases in witness accuracy | Geiselman and Machlovitz, 1987 | Scheflin et al., 1999 |
| Witness age: children | 94% | Increases likelihood of false IDs in young witnesses | Pozullo and Lindsay, 1998 | Dickenson et al., 2005 |
| Witness age: adults | 50% | Increases likelihood of false IDs in old witnesses | Memon and Gabbert, 2003 | Mueller-Johnson and Ceci, 2004 |
| Verbal overshadowing | | Reduces identification accuracy | Schooler and Engslter-Schooler, 1990 | Meissner and Brigham, 2001b |
| Distinctiveness of culprit | 32% | Increases accuracy with distinctive faces | Vokey and Read, 1992 | Shapiro and Penrod, 1986 |
| Lineup instructions | 98% | Unbiased instructions lower false identifications from TA lineup with lowering accuracy from TP lineups | Malpass and Devine, 1981a | Steblay, 1997 |
| Double-blind lineups | | Increase lineup identification accuracy | Haw and Fisher, 2004 | Russano et al., 2006 |
| Foil selection | 71% | Match-to-description strategies increase ID accuracy | Luus and Wells, 1991 | Wells and Olson, 2003 |
| Lineup presentations | 81% | Sequential lineups reduce false IDs | Malpass and Devine, 1981a | Steblay et al., 2001 |
| Showups | 81% | Increased risk of misidentification | Yarmey et al., 1996 | Steblay et al., 2003 |

(*Continued*)

**Table 1** (Continued)

| *Variables* | *Expert agreement*[a] | *Major results* | *Representative study* | *Review study* |
|---|---|---|---|---|
| Postidentification feedback | | Increases witness confidence without increasing accuracy | Wells and Bradfield, 1998 | Douglass and Steblay, 2006 |
| Suspicion inducement | | Reduces the inflation effect of postidentification feedback | Neuschatz et al., 2007 | Fein et al., 1990 |
| Mug shot exposure | 95% | Exposure to mug shots reduces identification accuracy | Gorenstein and Ellsworth, 1980 | Deffenbacher et al., 2006 |
| Cognitive interview | | Increases in witness accuracy without increases in inaccurate information | Fisher et al., 1989 | Powell et al., 2005 |

[a]This column represents the percentage of experts that agree that research on the variable is reliable. Those variables that do not have percentages in the testify and agreement columns were not included in the Kassin et al. (2001) survey.

index of the extent to which the findings are generally accepted in the scientific community.

Although this chapter focuses on estimator and system variables in eyewitness identification, note that these subsets of variables do not fully capture the breadth of research on eyewitness identification. Considerable research has also explored the effectiveness of safeguards designed to protect defendants from erroneous conviction resulting from mistaken eyewitness identification. This research has examined, for instance, the effectiveness of the presence of counsel at lineups, motions to suppress identification testimony, cross-examination, expert psychological testimony, and judges' instructions (see Van Wallendael et al., 2007, for a review). Underlying much of this research are assumptions concerning the extent to which laypeople (jurors) and legal practitioners (attorneys and judges) are sensitive to the factors that are known from the research to influence the accuracy of eyewitness identification, and the studies test these assumptions.

## 2.44.2 Estimator Variables Affecting Eyewitness Identification

### 2.44.2.1 Exposure Time

Witnesses typically identify suspects based on appearance, so it is reasonable to expect that longer and clearer viewing times lead to better memory and, therefore, enhanced identification accuracy. The literature on facial recognition certainly supports this assertion, as it has been consistently found that longer exposure leads to enhanced facial recognition (Ellis et al., 1975; Shapiro and Penrod, 1986; MacLin et al., 2001). To illustrate, Memon et al. (2003) exposed 64 young adults (ages 17–25) and older adults (ages 59–81) to a videotaped reconstruction of a robbery in which the perpetrator's face could be seen for either 12 s or 45 s. Each witness then attempted to identify the robber from a robber-present or robber-absent photoarray. Exposure duration had a significant impact on identification accuracy. Ninety-five percent of the young adults and 85% of the older adults made correct identifications from the robber-present photoarrays when the robber was exposed for 45 s, but only 29% of the young adults and 35% of the older adults made correct identifications when the robber was exposed for 12 s. Similarly, 41% of the younger adults and 50% of the older adults made false identifications from the robber-absent photoarrays when the target was exposed for 45 s, but 90% of the younger adults and 80% of the older adults made false identifications when the robber was exposed for only 12 s.

Shapiro and Penrod (1986) meta-analyzed 128 studies of face recognition and eyewitness identification involving over 17,000 participants. They examined the effects of exposure time in two different ways: They coded each study for exposure time and examined the impact of exposure time across studies (while controlling for other study characteristics), and they examined the average effects of exposure time within the subset of studies within which exposure time was directly manipulated. Both approaches revealed the expected relations between exposure time and identification accuracy. The respective hit rates for the long and short exposure time conditions were 69% and 57%. The respective false alarm rates were 34% and 38%. As exposure time increased there was a concomitant increase in the hit rate but no increase in false alarms.

Nevertheless, there are some qualifications to the effect of exposure time. Read et al. (1990b), for example, found that increased exposure time enhanced facial recognition when the face did not change from study to test. When slight variations in facial features occurred from study to testing, increased exposure did not improve recognition accuracy. They explained these findings by suggesting that increased exposure allows for encoding of more specific facial features, and the reliance on this information is only helpful at test if those features are still present in the target face at the time of retrieval. To the extent that features cue changes, more exposure time was found by Read et al. to be deleterious of facial recognition accuracy.

### 2.44.2.2 Changes of Appearance and Disguises

To what extent does a perpetrator's change in appearance from the time of the crime to the identification influence a witness's ability to identify him? The influence of changes in appearance on identification accuracy has been examined in several ways. The second author and his colleagues (Cutler et al., 1986, 1987a,b; Cutler and Penrod, 1988; O'Rourke et al., 1989) examined the effect of wearing a hood or baseball cap to cover the hairline of the culprit. In these studies, witnesses watched videotaped crimes and later attempted lineup identifications. In half of the videotaped crimes, the perpetrator wore a cap, while in the other half, his head was uncovered. In each of six studies the percent of correct identification decisions (including both target-present and target-absent lineups) was higher when the perpetrator's head was uncovered. The average performance levels across the six studies, which involved over 1300 eyewitness identifications, was 57% correct when uncovered versus 44% when a hat was worn (Cutler, 2006).

Whereas Cutler and colleagues examined deliberate attempts to disguise one's physical characteristics, Read (1995) examined the impact of more moderate and less invasive changes in appearance in a field study. In this study, two women, at separate times, approached a sales clerk. The first woman asked if her daughter had been in the store because they had arranged to meet at a specified time. The daughter entered the store 15 minutes later and asked the same store clerk if her mother had been in the store and asked for her. The daughter wore her glasses and had her hair pulled back from her face when she interacted with the clerk. Two days later the clerks were asked to identify the daughter from one of two lineups. In one lineup, the daughter's appearance was not changed, while in the other, her appearance was altered (no glasses, hair loose). It is important to note that even though the daughter's appearance was changed she still matched the general description given by the clerks. Consistent with the results reported by Cutler and colleagues, the changed appearance impaired subsequent lineup identification. Read found similar results in a subsequent study (Read et al., 1989)with a male confederate who changed his appearance by removing his facial hair between the crime and the lineup. In further support of these results, Hockley et al. (1999) found that presence or absence of glasses impaired facial recognition to the extent that there was a mismatch at study and test.

Appearance changes can occur naturally as a result of aging, for example, when a suspect is apprehended several months or years after a crime. Read et al. (1990b) examined the effect of such age changes on identification accuracy. Participants viewed black-and-white high school yearbook photos of students taken 2 years apart, in grades 10 and 12. Matched pictures were rated for appearance change by independent raters, and appearance change ratings were inversely associated with recognition accuracy. In Experiment 1, recognition accuracy was highest in the pairs of high similarity (54.5% correct) and lowest in the low-similarity pairs (32.6% correct). Furthermore, when two photos were highly similar, performance increased with exposure time.

Together, these results demonstrate that appearance changes resulting from deliberate attempts to mask features, modest changes in hairstyles and facial hair, and the natural processes of aging tend to impair identification accuracy. Conclusions from the studies of appearance change conform to the encoding specificity principle (Hunt and Ellis, 1974; Tulving, 1983). The encoding specificity principle states that the best memory performance occurs when the stimulus material at encoding matches the items at retrieval. When applied to appearance changes, we would predict, in accordance with this principle, that changes in appearance from the event (encoding) to the identification (retrieval) negatively impact identification accuracy.

### 2.44.2.3 Own-Race Bias

The own-race bias (ORB), also known as cross-race effect or other-race effect, refers to the conclusion that members of one's own race are more accurately recognized when compared to members of other races (Kassin et al., 1989). Though the majority of studies of the ORB have utilized White and Black participants, the consistency of this effect has been demonstrated across various racial and ethnic groups (Luce, 1974; Carroo, 1986). To illustrate, Platz and Hosch (1988) conducted a field study in which White, Black, and Hispanic customers visited convenience clerks and interacted with 90 White, Black, or Hispanic clerks. Within 2–3 h following each visit, an experimenter asked each clerk to identify the customers from photoarrays. Witnesses of each racial group demonstrated the ORB. White clerks were more likely to correctly recognize White customers (53.2%) than Black (40.4%) or Mexican (34%) customers. Black clerks were more likely to correctly recognize Black (63.6%) than White (54.6) or Hispanic (45.4%) customers. Hispanic clerks were more likely to correctly recognize Hispanic (53.6%) than White (35.7%) or Black (25%) customers.

The reliability of the ORB was examined by Meissner and Brigham (2001a), who meta-analyzed the results of 31 separate studies involving 91 separate experimental tests of own-race versus same-race identifications. The studies included over 5000 participants. Across all studies, eyewitnesses were 1.4 times more likely to correctly identify members of their own race than members of other races, and they were 1.56 times more likely to falsely identify members of other races than members of their own race. White participants demonstrated a significantly larger ORB when compared with Black participants but only with respect to false identifications. With respect to correct identifications, Whites and Blacks showed the same ORB. Exposure time moderated the ORB such that the magnitude of the ORB was inversely associated with exposure time.

Scholars with interests in the ORB have drawn upon various social-cognitive approaches (including racial attitudes, physiognomic homogeneity, interracial contact, schema theory, and perceptual learning theory) in their attempts to better understand its causal mechanisms. This research casts doubt on the underlying roles of racial prejudice and physiognomic homogeneity as explanations. Although racial attitudes may not have a direct influence on the ORB, several studies have found a correlation between racial attitudes and amount of interracial contact, a factor that, as noted later, does seem to influence the ORB effect (Brigham, 1993; Slone et al., 2000).

Considerable ORB research has examined the role interracial contact plays in reducing the ORB effect. Contact has been hypothesized to lessen the need to rely on stereotypical responses and to motivate people to accurately recognize members of other racial groups (Malpass, 1981b, 1990). The majority of the studies examining the contact hypothesis give some evidence in support of these predictions. For example, Cross et al. (1971) found that segregated neighborhood residents displayed a significantly greater degree of ORB than residents from desegregated neighborhoods. Further support for the contact hypothesis was obtained in the aforementioned meta-analysis (Meissner and Brigham, 2001a).

The contact hypothesis enlightens our understanding of certain social aspects that influence the ORB effect. Nevertheless, the contact hypothesis fails to account for the cognitive mechanisms by which it operates. To understand the cognitive mechanisms behind the ORB effect, researchers (e.g., Malpass, 1981a) have drawn upon Gibson's (1969) perceptual learning hypothesis. Perceptual learning and differentiation are acquired skills that enable an individual to efficiently extract pertinent information from the environment by experience and practice through focused attention toward invariant cues within certain stimulus sets (Gibson, 1969). Applied to the ORB, people are able to discriminate own-race faces more accurately because they can more efficiently extract invariant cues from own-race faces than other-race faces. Furthermore, these invariant cues are not necessarily predominant in other-race faces, resulting in decreased performance in recognition of other-race faces (Meissner and Brigham, 2001a).

#### 2.44.2.4 Stress Experienced by the Eyewitness

Witnessing a crime can be a highly stressful event, particularly if the witness is a victim or is in serious danger. Stress is commonly identified as a potentially influential factor affecting identification accuracy. Interestingly, lay opinion about the effect of stress is mixed. Many people think extreme duress improves identification accuracy, while others believe it impairs memory (Schmechel et al., 2006). This prevalence of conflicting lay opinions underscores the need for empirical research examining the impact of stress.

Stress is defined as the perception of the potential threat of injury or death to oneself or to another person (Thompson et al., 1998). Empirical examinations of the impact of extreme stress are made difficult for obvious reasons: A proposal to simulate extreme stress in the eyewitness laboratory would be risky business and would understandably meet with considerable resistance by university ethics review committees. Researchers have therefore had to rely on less evasive – and less ecologically valid – manipulations of stress. Some researchers have manipulated stress by exposing witnesses to violent versus nonviolent videotaped crimes (e.g., Clifford and Hollin, 1981). Others have conducted field research and examined actual witnesses to crime. Yuille and Cutshall (1986) interviewed witnesses to a murder and found that those who reported being under the greatest amount of stress were more accurate than those who reported experiencing less stress. Complementing this finding, Reisburg et al. (1988) and Wagenaar and Groeneweg (1990) interviewed participants about recently experienced ordinary events and traumatic events. When describing traumatic events, participants expressed more vivid memories, including the specifics of the event, than when describing ordinary events. Unfortunately, because the experimenter was not privy to the actual events described, the accuracy of these flashbulb memories could not be verified.

Morgan et al. (2004) investigated the impact of extreme versus mild stress on identification accuracy in a sample of 530 active-duty military personnel who participated in military survival school training. The training protocol required some participants to undergo a high-stress interrogation with real physical confrontation and a low-stress interrogation without real physical confrontation. Others experienced either high- or low-stress interrogations. At the end of training, all participants attempted to identify their interrogators from lineups which were either live (simultaneous presentation) or photographic (simultaneous or sequential presentation). Among eyewitnesses shown live, interrogator-present lineups, correct identification rates were much higher following low-stress interrogation (62%) than following the high-stress condition (27%). The same pattern held for simultaneously presented perpetrator-present photographic lineups (76% vs. 36%) and sequentially presented perpetrator-present photographic lineups (75% vs. 49%, respectively).

The effects of stress were further confirmed in a meta-analysis (Deffenbacher et al., 2004) that examined 27 separate tests of the impact of stress on identification accuracy and 36 tests on the impact of description accuracy. Across all studies of identification accuracy, stress inversely and significantly affected the likelihood of correct identification ($h = -0.52$, corresponding to correct identification rates of 0.19 in the high-stress conditions and 0.34 in the low-stress conditions). Stress had a negligible impact on performance in target-absent lineups ($h = 0.01$, corresponding to a 1% difference in false identification rates). Stress also impaired description accuracy across studies ($d = -0.31$).

Although the meta-analysis shows that extreme stress impairs eyewitness memory, the relation between stress and eyewitness memory is not thought to be linear. In one of the earliest reviews of the research on stress and eyewitness memory, Deffenbacher (1980) concluded that the research across 21 studies conformed to the Yerkes-Dodson law (Yerkes and Dodson, 1908). This law states that the effects of stress can be graphed as an inverted U so that with slightly increased levels of stress, there is improvement with memory. However, as stress increases, it reaches an apex and then begins to have a negative impact, resulting in poor encoding and recollection.

Easterbrook's cue-utilization theory has been posited as an explanation for the impact of stress on memory. According to this theory, as stress surpasses moderate levels, attention is diverted from the details of the event to the anxiety (Christianson, 1992; Easterbrook, 1959). It is further hypothesized that because less attention is available for a stressful event, there is a narrowing of focus so that the person allocates more attention to the most informative data (e.g., a weapon in a crime). This leads to the centralization of focus that occurs during highly arousing events. While there has been some debate as to the effects that stress has on the memory of an event, it is clear that information is encoded differently during a stressful event than during a nonstressful event, so that stressful events improve memory for certain aspects of the event while impairing memory for other aspects of the event.

### 2.44.2.5 Weapon Focus

The presence of a weapon is thought to lead an eyewitness to attend to the weapon, leaving less attention to deploy toward other information (Loftus et al., 1987; Mitchell et al., 1998; Pickel, 1998). Weapon focus, therefore, should impair the eyewitness's ability to identify the perpetrator. Put another way, the presence of a weapon is thought to create competition between the weapon and the assailant's face and physical characteristics. Does the presence of a weapon actually impair identification accuracy? In a study by O'Rourke et al. (1989), 120 community members (members of a church group, parents of a local Boy Scouts troop, and undergraduate summer school students) viewed a videotaped enactment of a crime. In half of the crimes, a handgun was visually present, and in the other half, the gun was hidden from view in the perpetrator's coat. One week later, each eyewitness attempted to identify the perpetrator from a lineup. Percent of correct decisions on the lineup test was 55% among witnesses who did not see the weapon but 37% for those who did see the weapon – a statistically significant difference. The weapon focus effect increased the likelihood of false identification and decreased the probability of correct identification.

Steblay (1992) meta-analyzed 19 empirical studies of the weapon focus effect. Of the 19 studies she examined, six demonstrated a significant weapon focus effect while 13 found null results. No study revealed enhanced memory for the presence of a weapon. When the results of these studies were combined, the weapon focus effect for identification accuracy was significant but relatively small in magnitude (corresponding to a difference of about 10% in identification accuracy rates). The effect was larger on description accuracy, however. The weapon focus effect was larger among studies that used more ecologically valid research designs.

The most direct support for the weapon focus effect comes from a study by Loftus et al. (1987). They employed a corneal reflection device which tracks both the direction and duration of eye movements. Participants watched slides that included a person approaching a restaurant counter with either a check or a weapon. They found that people looked at the weapon longer and more often than they looked at the check. In addition, participants' memories were significantly worse in the weapon condition compared to the check condition.

One of the more popular explanations for the weapon focus effect is that people focus their attention on information that is meaningful and not on the weapon *per se*. When a weapon is involved, it becomes the meaningful information (Loftus et al., 1987; Brown, 2003). Thus, the eyewitness focuses on the gun or the central details of the crime, while largely ignoring the peripheral information such as clothing or facial features of the perpetrator. Other researchers, in contrast, have theorized that the weapon focus effect occurs not because the weapon is stressful or highly arousing but rather because the weapon is unusual. To examine this hypothesis, Pickel (1998) had participants view a videotape in which a target was empty-handed or carrying something threatening or unusual. Her results indicated that it was the unusual object – not the dangerous object – that drew witnesses' attention. In other words, the appearance of a gun in a situation in which one would expect its presence, such as a hunting trip, would not lead to the traditional weapon focus effect. Pickel's explanation received further support in a study (Pickel, 1999) showing that the same weapon elicited a larger weapon focus effect when carried by a preacher (an unusual event) than when carried by a police officer (a typical event). Thus, Pickel's research supports the idea that unusualness of the object and situation, and not the mere presence of a weapon, are critical for obtaining the weapon focus effect.

### 2.44.2.6 Eyewitness Confidence

The confidence accuracy relationship (CA) is one of the most studied variables in eyewitness research. Common sense tells us that highly confident witnesses are more likely to be accurate than less confident witnesses (Schmechel et al., 2006). The courts have gone so far as to establish witness confidence as one of the indicators jurors should use to evaluate the accuracy of eyewitness identifications (Neil v. Biggers, 1972).

Does the relation between confidence and accuracy conform to common sense? Many studies of eyewitness identification have assessed witness confidence as a primary or secondary variable. Correlations between confidence and accuracy (or comparable indices of association) are reported in many studies. For example, in a study conducted by Cutler et al. (1987a), 165 students watched a videotaped enactment of a robbery and later attempted to identify the thief from videotaped lineups. Various aspects of the viewing conditions and lineup were manipulated. In all conditions, participants rated their confidence in the accuracy of their identifications immediately following their identification decisions. Across all conditions, the correlation between confidence and accuracy was significant but relatively weak ($r = 0.20$; $p < 0.05$) in magnitude.

The correlations between confidence and identification accuracy have been subjected to several meta-analyses over time (Deffenbacher, 1980; Wells and Murray, 1984; Shapiro and Penrod, 1986; Bothwell et al., 1987; Cutler and Penrod, 1989; Sporer et al., 1995). Sporer et al.'s (1995) was the most recent and comprehensive meta-analysis. Their analysis included 30 studies and over 4000 witnesses. The average correlation across studies was 0.29. The correlation was significantly higher among witnesses who made positive identifications than among witnesses who rejected their lineups ($r = 0.41$ vs. 0.12).

The oft-found modest correlation between confidence and accuracy begs explanation, as it is inconsistent with theoretical decision-making models (e.g., signal detection theory) that would predict a strong relation between confidence and accuracy (Brewer et al., 2005; Libuser and Ebbesen, unpublished data; Ebbesen and Wixted, unpublished data). The explanation, we believe, is that although eyewitnesses are somewhat sensitive to the accuracy of their identifications, their expressions of confidence are influenced by cognitive, personality, and social factors that are independent of identification accuracy. Any factor that influences confidence independent of accuracy should attenuate the relation between confidence and accuracy.

This very general explanation has received support in the eyewitness literature. For example, with respect to cognitive factors, Deffenbacher (1980) offered the optimality hypothesis as an explanation for the weak relation between confidence and accuracy he observed in his review. Optimal viewing conditions, according to this hypothesis, improve both accuracy and the relation between confidence and accuracy, for under optimal conditions, witnesses should give more accurate meta-cognitive judgments. The optimality hypothesis has received support in meta-analytic reviews (Deffenbacher, 1980; Shapiro and Penrod, 1986; Sporer et al., 1995), but support is not universal (Penrod and Cutler, 1995).

Kassin (1985) reasoned that the failure to find a relation between confidence and accuracy might reflect an inability to successfully employ the intrinsic and extrinsic cues that exist with memory traces. More specifically, witnesses may not be aware of the diagnosticity of the cues that exist in remembering and therefore cannot successfully apply those cues to gauge confidence estimates. For example, in their seminal article, Nisbett and Wilson (1977) have shown that people are poor at both identifying reasons for their behaviors and expressing their thought processes. Kassin (1985) believed that making participants aware of their meta-cognitive cues by showing them videos of their own identifications would in turn increase the confidence-accuracy relation. To this end, Kassin (1985) recorded participants during a lineup procedure and subsequently had participants report their confidence. Some of the participants watched a video of their identification before they made their confidence estimates, and others did not. The results indicated that those who watched the identification videos of themselves demonstrated a higher confidence-accuracy correlation.

#### 2.44.2.7 The Application of Estimator Variables: Expert Testimony

The primary application of estimator variable research is expert testimony about the psychology of eyewitness memory. With increasing frequency, psychologists are called upon to testify in criminal cases about the reliability of eyewitness identification. In the aforementioned survey of eyewitness experts (Kassin et al., 2001), the 64 experts surveyed reported being invited to testify on 3370 occasions. They agreed to testify in 1373 trials and actually testified in 960 trials. This activity represents a substantial increase over the results obtained in a previously published survey (Kassin et al., 1989). In this previous survey, experts reported being invited to testify in 1268 trials.

The typical content of expert testimony varies from jurisdiction to jurisdiction, and even from courtroom to courtroom within a jurisdiction, for judges have considerable discretion in determining what testimony will be allowed in a given trial. Generally speaking, experts discuss how memory works (e.g., the stages of memory, reconstructive processes), dispel myths about memory (e.g., memory does not work like a video recorder), and describe relevant estimator and system variables in the case that could influence memory. For example, an expert in a given case might discuss the influence of high stress, weapon focus, the ORB, and suggestive lineup instructions. Experts are not permitted to comment on the accuracy of the eyewitness.

Expert testimony about the psychology of eyewitness memory is in some respects controversial. Admissibility of the expert testimony varies considerably from state to state and within the federal court system. When expert testimony is not admitted, the single most common reason given is that the content of the testimony is merely a matter of common sense – a conclusion that is seriously challenged by empirical research (Schmechel et al., 2006). Some scholars (e.g., Konecni and Ebbesen, 1986; Elliott, 1993) have questioned the extent to which eyewitness studies, which are mainly conducted in the laboratory, generalize to actual crimes and therefore challenge the appropriateness of expert testimony. Such critics have found themselves in the role of opposing experts on occasion. Although the vast majority of cases in which experts testify are criminal cases, and the expert is almost always proffered by the defense (Kassin et al., 2001), occasionally the prosecution will offer an opposing eyewitness expert. The experts surveyed in Kassin et al.'s study reported that in the 960 trials in which they testified, an opposing expert testified in 76 cases (8%). In such cases, the opposing expert might challenge the generalizability of the research, question the extent of expert agreement about certain factors, or challenge the defense expert's conclusions based on the literature. Another concern about expert testimony is its actual effect on the jury. Empirical investigations of the impact of expert testimony on juror decisions show a range of effects, including making jurors more skeptical about eyewitness identification (Leippe, 1995), enhancing juror sensitivity to some of the factors that influence identification accuracy (Cutler et al., 1990), and no effect at all (Devenport and Cutler, 2004). In all probability, the effects of expert testimony are complex and qualified by other factors (e.g., Leippe et al., 2004).

Controversial issues notwithstanding, expert testimony is becoming an increasingly popular safeguard against erroneous conviction in cases in which eyewitness testimony figures prominently. The quality of testimony rests on the foundation of eyewitness memory research on estimator and system variables.

## 2.44.3 System Variables Affecting Eyewitness Identification

### 2.44.3.1 Lineup Instructions

Considerable attention has been devoted to understanding the impact of lineup instructions on identification accuracy. In their seminal article, Malpass and Devine (1981a) examined the effect of biased and unbiased lineup instructions on identifications from target-present and target-absent lineups. By not containing an explicit option to reject the lineup, biased instructions implied that participants were to choose someone from the lineup, whereas unbiased instructions provided a no-choice option. Malpass and Devine found that accurate identifications were not affected by instruction type when the target was in the lineup (75% vs. 83% accurate for biased and unbiased instructions, respectively). In contrast, false identifications from target-absent lineups were significantly higher in the biased-instructions condition (78%) than in the unbiased condition (33%). Thus, biased instructions increased the likelihood of false identification without influencing correct identification rates.

Steblay (1997) meta-analyzed the studies examining the effects of lineup instructions on identification accuracy. Employing 18 different studies in her analysis, she found a clear, consistent pattern that replicated the results of Malpass and Devine (1981a). That is, with target-absent lineups, unbiased instructions led to fewer false identifications (35%) than did biased lineup instructions (60%). The rates of correct identification from target-present lineups were virtually identical for unbiased (54%) and biased (53%) instruction conditions. While the impact of biased lineup instructions on false identifications is generally accepted (Kassin et al., 2001), the effect of biased lineup instructions on correct identifications is less clear, as noted by Clark (2005), who re-analyzed the studies examined by Steblay (1997) and reached a different conclusion.

### 2.44.3.2 Blind Administration of Lineups

According to Wells and Olson (2003), the person who typically conducts the lineup is the police officer assigned to the case. This officer usually constructs the lineup as well (i.e., chooses the fillers and the position of the suspect). Although having the investigator assigned to the case conduct the lineup test may seem perfectly reasonable from the perspective of efficiency and police administration, many years of psychological research on experimenter bias and expectancy effects call into question the value of this practice. Put succinctly, the investigator, who knows which lineup member is the suspect, can advertently or inadvertently convey the correct answer to the eyewitness and therefore influence her identification decision. When evaluating a positive identification under these circumstances, it is impossible to know whether the identification is the product of the witness's memory for the perpetrator, influence by the investigator, or some combination of the two. Given that the purpose of the lineup is to test the hypothesis that the suspect is the perpetrator, ruling out alternative explanations for positive identifications, such as influence by the investigator, is highly desirable. Thus, for the same reasons that we ensure that our experimenters are blind to the participant's experimental condition – or our physicians are blind to the assignment of patients to treatment versus placebo conditions in clinical trials – investigators would be well advised to ensure that lineups are conducted by investigators who do not know which lineup member is the suspect. This blind administration procedure allows the authorities to rule out investigator influence as an explanation for a witness's identification.

Although the need for blind lineups can be sufficiently established based on the vast literature on expectancy effects (Haw and Fisher, 2004), some eyewitness researchers have nevertheless empirically compared eyewitness identifications from blind versus nonblind procedures. In a study conducted by Garrioch and Brimacombe (2001), participants arrived in pairs and were assigned the roles of lineup administrator and witness to a crime. The lineup administrator was instructed on how to conduct the lineup, was told the position of the suspect, and was then instructed not to communicate this position to the witness. Unbeknownst to the lineup administrator, the lineups did not contain the perpetrator. Witnesses watched a videotaped crime and were reunited with their respective lineup administrators for the identification task. The results indicated that participants were more confident in their selection when they chose the target consistent with the administrators' expectations as compared to participants who chose an alternative lineup member. When asked if there was any outside influence that affected their decision, witnesses responded that there was none. Thus, even when lineup administrators were explicitly asked not to influence the witness, they were still able in some way to cue and influence the witness's identification decisions.

Phillips et al. (1999) compared blind versus nonblind administration in simultaneous and sequential lineups. Their study demonstrated the biasing influence of nonblind administration, but only for sequentially presented lineups. Haw and Fisher (2004) varied the amount of contact between the lineup administrator and the witness during the lineup test. They found that the witness was less likely to make a decision that was consistent with the lineup administrator's expectations if the amount of contact between the two parties was limited (the administrator was present but did not speak). This was true regardless of whether the lineup was simultaneous or sequential or whether the target was present or absent.

The use of blind administration raises some additional questions. For example, if a blind administrator shows a lineup to a witness and the witness makes a positive identification, is that investigator still blind? Should that investigator be allowed to show the lineup to another witness? There are often multiple eyewitnesses, so the impact of a positive identification on subsequent lineups is worthy of examination. Douglass et al. (2005) empirically examined this issue. They had participants, in the roles of lineup administrators, conduct the same target-absent lineup twice, once to a confederate witness and once to a participant witness. The authors were interested in determining if the lineup administrator's knowledge of the confederate selection would influence the selection of the second witness. Their results revealed that if the confederate witness selected a suspect with low confidence, then the lineup administrator influenced the participant witness to select the same person. Furthermore, even though the participant witness's selection was influenced, the influence was so subtle that independent observers could not detect it when watching the tainted identification procedure. Thus, it is clear that not only should lineup administrators be blind to the identity of the suspect, but they should also be replaced with another blind administrator after an identification is made, for then the administrator of the first lineup is no longer blind to the identity of the suspect.

In their recent review of both published and unpublished research on blind administration, Russano et al. (2006) concluded that the results are mixed, with some studies demonstrating the biasing effects of nonblind procedures and others failing to do so. Given the general acceptance of expectancy research, these mixed results are somewhat surprising. Russano et al. posit that the mixed results are in part due to the difficulty of effectively simulating investigations in the laboratory, the subtlety of the influence, the magnitude of the effect (which might be small), the use of students posing as lineup administrators (as opposed to more experienced police investigators), and, more generally, the dearth of research on the phenomenon.

### 2.44.3.3 Filler Selection

Fillers, which are sometimes referred to as foils or distractors, are innocent people included in the lineup with the suspect. Luus and Wells (1991) outlined some of the major functions of fillers in a well-constructed, fair lineup. Given that fillers, by definition, are known to be innocent, any selection of a filler is a known error, thereby giving the lineup administrator information regarding the accuracy of the eyewitness. The filler also serves as a control for guessing: the suspect should not be chosen more often than each of the fillers if the witness has no memory of the culprit. A witness with no memory of the culprit should choose the suspect at a rate of 1/N (where N is the total number of lineup members) if the lineup is not biased. Another function of the fillers is to ensure that the identification is made based on memory rather than on logical deduction (e.g., the culprit had a beard and only one person in the lineup has a beard so that must be him).

There are at least two strategies utilized in selecting fillers: match-to-similarity-of-suspect (MS) and match-to-description-of-culprit (MD) (Luus and Wells, 1991). The former involves selecting fillers who physically resemble the suspect. The latter involves selecting fillers based on their match to the witness's description of the perpetrator. How do the different strategies for choosing fillers achieve these aforementioned purposes of having fillers in the lineup? Wells (Luus and Wells, 1991) explains the benefits of the MD approach over the MS approach. The MD approach protects against the witness identifying the suspect based merely on her memory for her description of the perpetrator. For example, if the witness remembers some unique features of the perpetrator and the suspect is the only one in the lineup that possesses those features, the witness can deduce which one is the suspect. Deduction, like guessing, is not the preferred cause of a positive identification. By contrast, using the MD strategy, fillers are chosen because they possess those unique features, and the witness cannot identify the perpetrator merely on the basis of those features, and the witness is therefore required to rely on memory when making an identification (the preferred cause of a positive identification).

Using the MS strategy does not provide this same protection against mistaken identification. In theory, the MS strategy poses great risk to the innocent suspect who was arrested because he looks like the perpetrator. Consider a situation in which an innocent suspect becomes a suspect because he matched the description of the perpetrator. Of course, the suspect will not perfectly resemble the perpetrator. There will be some natural variation in their physical characteristics. Now suppose that fillers are selected because they match the suspect (i.e., the MS strategy). Because the suspect did not perfectly resemble the perpetrator and the fillers did not perfectly match the suspect, it is reasonable to infer that the fillers will on average look less like the perpetrator than does the suspect. If the witness seeks to identify the suspect who looks most like the perpetrator, it will usually be the innocent suspect. Clark and Tunnicliff (2001) refer to this ironic consequence of the MS strategy as the backfire effect.

According to Luus and Wells (1991), the MD strategy does not suffer from the backfire effect because fillers are matched on the relevant descriptors provided by the witness. In the target-absent lineup, all the relevant features (i.e., those mentioned in the description of the perpetrator) should appear in all members. Thus, the MD strategy leads to similar amounts of correct identifications when the target is present and fewer false identifications when the target is not present, as opposed to the MS strategy.

Beneficial effects of the MD strategy, however, are not universally obtained. Lindsay et al. (1994) noted that the MD strategy is less effective when the description of the culprit is incomplete. This study tested three types of lineups: MS, MD, and biased MD. In the biased condition, the fillers were chosen so that they matched the features mentioned in the witness description but were maximally different in appearance to the culprit. For example, if hair color was not mentioned as a feature by the witness, then the distracters could have a hair color that differed from that of the suspect. This biased condition produced more false identifications of the suspect than the other two conditions. Thus, it appears that the MD is the best strategy as long as the fillers selected match the description and also match the appearance of the culprit on some general overall characteristics such as race, hair color, or presence or absence of facial hair.

### 2.44.3.4 Lineup Presentation

Considerable research has been devoted to the examination of various methods for presenting lineups. The most commonly examined presentation methods are simultaneous and sequential. In simultaneous lineups the witness is shown all of the lineup members at the same time and is asked which one, if any, is the perpetrator. In the sequential lineup the witness views lineup members one at a time and makes an identification decision (yes/no) for each lineup member as he is presented. The witness is not told in advance how many lineup members are in the lineup.

Why should performance differ as a function of lineup presentation method? Wells (1984) hypothesized that the simultaneous method induces a cognitive process, known as relative judgment, in which the witness compares each of the lineup members in order to determine which one 'most' resembles his memory of the perpetrator. This process would lead a witness to compare each lineup member to the next using a process of elimination (e.g., "Number 2 looks more like the perpetrator than Number 1 does"). Given that one lineup member will inevitably better resemble the perpetrator than the other lineup members, the relative judgment strategy tends to produce positive identifications, whether the actual perpetrator is present or absent, thus increasing the likelihood of false identifications from target-absent lineups.

Recognizing the limitations of the relative judgment strategy, Lindsay and Wells (1985) developed the sequential method as a means of discouraging relative judgment processing and encouraging absolute judgment processing. In absolute judgment processing, the witness compared each lineup member in the sequence to his memory for the perpetrator and makes an identification decision on the basis of the memory-lineup member match. To test their hypotheses concerning simultaneous and sequential lineups, Lindsay and Wells (1985) staged thefts before 243 undergraduates and in the same sessions had eyewitnesses attempt identifications from thief-present or -absent photoarrays. Half were shown simultaneous and half were shown sequential photoarrays. When the thief was present, the percentage of correct identifications was comparable for simultaneous and sequential lineups (58% vs. 50%, respectively). When the thief was absent, simultaneous lineups produced more false identifications than did sequential lineups (43% vs. 17%).

To further test this theory, Lindsay (1991) compared each of the lineups and then asked people to report if they used a process of elimination (relative) or if the perpetrator popped out (absolute). He found that the accurate participants were more likely to indicate that they used absolute judgment in their decision process. In addition, some research has suggested that self-reported use of an absolute judgment process as opposed to a relative judgment process postdicts identification accuracy (Dunning and Stern, 1994).

How reliable is the effect of presentation method on identification accuracy? Steblay et al. (2001) addressed this question by conducting a meta-analysis of 23 studies comparing simultaneous and sequential presentation, nine of which were published and 14 of which were unpublished. In data from target-present lineups, participants were more likely to correctly choose the target (50% vs. 35%) and less likely to make a false rejection (26% vs. 46%) from simultaneous lineups. There were no differences between the two lineup presentation methods for filler choices. In target-absent lineups, sequential lineups garnered more correct rejections (72% vs. 49%) and fewer false identifications (28% vs. 51%). Overall, participants were more likely to positively identify a suspect from a simultaneously presented lineup than from a sequentially presented lineup (74% vs. 54%). Note that the effect of presentation was considerably larger on false identifications than on correct identifications. This means that, overall, sequential presentation produced identifications that were more diagnostic than did simultaneous presentation.

Although Steblay et al.'s (2001) meta-analysis reflects the state of the science concerning the effects of simultaneous and sequential presentation, the conclusion is not universally accepted. A critique of the meta-analysis by McQuiston-Surrett et al. (2006) identified some potentially important methodological issues that deserve consideration. Specifically, these authors observed that most of the significant results between the two procedures were produced in the same psychological laboratory. The inclusion of unpublished studies in the meta-analysis was also a concern for these authors. They call for greater attention to factors that may qualify the impact of sequential and simultaneous presentation.

The benefits of sequential lineups notwithstanding, not all researchers agree that the gains in lineup accuracy are due to relative versus absolute judgment processing, as originally proposed by Lindsay and Wells (1985). Clark and Davey's (2005) research found that identification decisions did not conform to predictions derived from relative- and absolute-judgment strategies. They included in the comparisons of simultaneous and sequential presentation conditions in which the targets were removed from the lineups without replacement. Clark and Davey reasoned that witnesses who adopt relative-judgment strategies would shift their identifications from the target to other fillers, whereas witnesses who adopt absolute-judgment strategies would shift their identifications from the target to lineup rejections. They found comparable degree of shifts from target identifications to filler identifications from simultaneously and sequentially presented lineups, thus casting doubt on the absolute-relative judgment explanations for the differences observed due to simultaneous and sequential lineups. By contrast, Meissner et al. (2005) demonstrated that the benefits of sequential lineup may be explained by a criterion shift. More specifically, sequential lineups induce the use of stricter criteria, which results in fewer false identifications without lowering correct identifications.

### 2.44.3.5 Showups

A showup is a one-to-one confrontation between the witness and the suspect in which the witness is asked if the suspect was the person who committed the crime. Psychologists have typically suggested that showups are suggestive and unreliable (Yarmey et al., 1994, 1996; Lindsay et al., 1997). In the aforementioned survey by Kassin et al. (2001) 74% of the eyewitness experts agreed with the statement "The use of a one-person showup instead of a full lineup increased the risk of misidentification" (see **Table 1**).

There are two theoretical arguments against using showup. First, a showup, by its very nature, provides only one option to the witness, making it difficult to distinguish identifications made from memory versus guessing, deduction, or social influence. A properly conducted photoarray provides better safeguards against these alternative explanations for positive identifications.

The second argument is that innocent fillers in the lineup that closely match the witnesses' description of the culprit improve lineup performance (Luus and Wells, 1991; Wells et al., 1994), as described earlier. It is thought that having fillers in the lineup that are reasonable alternatives forces the witness to closely scrutinize the lineup members and make more accurate decisions.

Do showups produce more false identifications than lineups? Gonzales et al. (1993) had a perpetrator enter the classroom and sit in the back row and steal the purse off of the instructor's desk. Participants were later shown either a live lineup or a live showup. In the showup condition, 30% correctly identified the perpetrator, where 67% correctly chose the perpetrator in the lineup condition. Furthermore, in the target-absent condition 92% in the showup condition correctly stated the perpetrator was not there, as compared to 38% in the lineup condition. Thus, the showups did not result in more mistaken identifications than lineups; however, Yarmey et al. (1994) have argued that when you take into account the guessing rate (15% vs. 16% showups and lineups, respectively), lineups produce more accurate lineup identifications with no differences in false identifications.

To further examine the difference in lineup versus showup performance, Steblay et al. (2003) meta-analyzed the existing 12 studies, which included 3013 participants. Overall, they found nonsignificant differences in identification performance between showups and photoarrays. Indeed, the rates of correct identifications from target-present lineups were nearly identical (47% and 45%, respectively). Contrary to expectation, there were significantly more correct rejections from showups than from lineups (85% and 57%, respectively). At least based on these data, therefore, the conclusion that showups produce more false identifications than lineups is not supported. Nevertheless, the first argument raised still holds: Showups provide poor safeguards against guessing, deduction, and social influence, all of which can explain positive identifications.

### 2.44.3.6 Postidentification Feedback

Postidentification feedback is any statement made to an eyewitness after he or she has selected a suspect from a lineup (Wells and Bradfield, 1998). For example, if Eileen Eyewitness picks out Scottie Suspect from a lineup, the administrator may say something like "Great, you got 'em." This comment may seem innocuous, but is it? Luus and Wells (1994) conducted one of the first studies that systematically investigated the effect of postevent feedback on retrospective certainty. Pairs of subjects watched a staged theft, made individual lineup identifications from a photo spread, and were subsequently given bogus postidentification feedback regarding their co-witnesses' alleged identification decisions. It is important to note that all of the witnesses who made positive identifications were incorrect, because they were all exposed to target-absent lineups. Although Luus and Wells gave nine different types of feedback, for the sake of brevity we will only address the confirmatory feedback (i.e., when the witness was told that they had selected the same person as the co-witness). Participants who were given confirmatory feedback expressed more confidence in their identification than witnesses given no feedback (8.77 vs. 6.90 on a nine-point scale) when later interviewed by confederates posing as police officers. It is important to note that this confidence inflation occurred even though participants were given no indication that the identification was correct. In the second experiment, participants role-playing jurors rated the (inaccurate) witnesses who received the confirmatory feedback as the most credible. Thus, confirmatory feedback increased witness confidence in their identifications and made their testimony seem more believable to jurors, and this occurred independently of the accuracy of the eyewitnesses.

In a related study, Wells and Bradfield (1998) examined the effects of postidentification feedback from a lineup administrator on retrospective eyewitness certainty. Their participants watched a clip from a security camera video and attempted to identify the target from a target-absent lineup. Following their identifications, some participants were told that they had selected the right person, while others were given no such feedback concerning their identifications. Participants who were given feedback reported that they paid more attention to the perpetrator, were more certain in their identification, and had a clearer view when compared to the subjects who were not given feedback.

The effects of postidentification feedback are robust and reliable. They have been demonstrated using a wide variety of dependent measures, as noted. The effects have been found to persist using a 1-week retention interval (Neuschatz et al., 2005) and have been observed in witnesses of varying ages (Hafstad et al., 2004).

Can the detrimental impact of postidentification feedback be mitigated? Wells and Bradfield (1998) suggested that eyewitnesses, at the time they make their identifications, do not make online judgments about how good of a view they had, how much attention they paid, or how certain they are in their identifications. When they are later asked about these issues, they base their responses on what is accessible in memory. Because participants do not make online judgments, they are forced to infer their confidence from the feedback that was given to them. To illustrate, an eyewitness might infer that if she was told that she was correct, she must have had a good view, paid attention, and been confident in her decision. Wells and Bradfield proposed that the postidentification feedback effect could be eliminated by forcing participants to think about their confidence, attention, and view at the time of the identification, thus giving them memory traces for these internal cues without having to rely on feedback from an external source.

To test this notion, Wells and Bradfield had participants give confidence ratings before and after the feedback manipulation. They argued that the confidence question would force participants to think about how certain they were and how good a view they had before they received the postidentification feedback. The results indicated that the feedback effect was mitigated in those participants who received the confidence question prior to the feedback. Wells and Bradfield referred to this as the confidence prophylactic effect. One problem with this effect is that, although it works if eyewitnesses are questioned immediately, its preventative effects seem to be short-lived. Neuschatz et al. (2007) found that the confidence prophylactic effect worked immediately but not after a 1-week retention interval. Given that the length of time between identification and trial is normally much longer than 1 week, the confidence prophylactic effect might not be an adequate safeguard against confidence inflation due to postidentification feedback.

Neuschatz et al. (2007) examined whether inducing suspicion about the postidentification feedback weakened its effect. Suspicion is the orientation in which the perceiver maintains the possibility that multiple causes may be influencing the actor's behavior and that the actor may be hiding something that might discredit the meaning of that action (Fein et al., 1990). Suspicion inducement has been found to reduce biases in studies examining the impact of prejudicial pretrial publicity and inadmissible evidence on jury decision making (Fein et al., 1997). In the experiment conducted by Neuschatz et al. (2007), participants viewed a video and were asked to identify a suspect from a target-absent photo lineup. Afterwards, some participants were informed that they selected the actual suspect, while others were given no information. Either immediately or after a 1-week retention interval, participants were led to another room by a different experimenter. Some participants who received feedback were given reasons to entertain suspicion regarding the motives of the lineup administrator. Subsequently, participants answered a questionnaire regarding their identification. The authors hypothesized that making the participant suspicious would lead the participant to question the validity of the feedback, thus adjusting their confidence in their witnessing experience. Neuschatz et al. found that suspicious perceivers did not demonstrate the confidence inflation effects typically associated with confirming feedback.

In summary, research converges on the conclusion that postidentification feedback influences eyewitness confidence and retrospective reports of the conditions under which they witnessed the event. Postidentification feedback, therefore, should serve to further attenuate the relation between eyewitness confidence and identification accuracy. Some research suggests that the postidentification feedback effect can be mitigated by assessments of confidence prior to postidentification feedback (at least when retention intervals are brief) and the inducement of suspicion concerning the source of the postidentification feedback.

### 2.44.3.7 The Application of System Variables: Lineup Reform

The aforementioned perfect storm resulted from, on the one hand, growing documentation of miscarriages of justice resulting from mistaken eyewitness identification and, on the other hand, a readiness on the part of eyewitness researchers to offer practical advice based on a large body of research on lineup techniques. What followed was a series of published recommendations, including the first white paper endorsed by the American Psychology-Law Society (Division 41, American Psychological Association) (Wells et al., 1998) and an influential United States Department of Justice report commissioned by Janet Reno, Attorney General at the time (Technical Working Group on Eyewitness Evidence, 1999). Following these published recommendations, the State of New Jersey was the first in the nation to adopt new guidelines for lineups. The guidelines adopted by the New Jersey Attorney General included such recommendations as (1) instructions that warn jurors that the perpetrator might not be in the lineup; (2) use of the match-to-description technique for selecting fillers; (3) sequential presentation of photoarrays; (4) the use of blind lineup administration; and (5) the assessment of eyewitness confidence immediately after the lineup and before witnesses are given confirming or disconfirming evidence about their identifications. These recommendations follow directly from the research literature. The State of North Carolina was the second state to develop and adopt new recommendations, and theirs were very similar to those adopted by New Jersey. Other states (Illinois, Minnesota) have experimented with these new techniques. Other states and cities (e.g., Virginia, Florida, Wisconsin, Boston, Seattle) are in the process of studying or implementing lineup reform.

Just as continuing research on estimator variables continues to inform expert witnesses and therefore lawyers, judges, and juries, research on eyewitness identification continues to inform psychologists who work with police and prosecutors to reform their identification procedures. Consider, for example, the influence of two recently published findings and the implications of these findings for practice. First, based on the research of Haw and Fisher (2004) described earlier, the amount of interaction between the lineup administrator and the witness should be held to a minimum. Second, the lineup administrator should not conduct the same lineup for witnesses tested in sequence. Being privy to the selection of one eyewitness can compromise the protection afforded by having administrators blind to the identity of the suspect, as the first identification may allow them to develop their own hypothesis as to the suspect's identity (Douglass et al., 2005).

## 2.44.4 General Conclusions

The foregoing review serves to illustrate how basic research on human memory can be applied to real-world phenomena, eyewitness memory in this case. Many years of research on eyewitness memory have positioned eyewitness researchers to offer practical advice in courtrooms and to police investigators charged with the responsibility of creating and administering lineups. The eyewitness research draws from traditional theories and methods of cognitive and social psychology and ultimately informs those disciplines in return.

Ideally, the next generation of eyewitness research will draw upon lessons learned in the field. The adoption of techniques developed and tested in the laboratory for use in the field should reveal new problems and questions that could not have been anticipated by laboratory researchers. For example, both authors of this chapter have served as expert witnesses in cases involving eyewitness identification. When providing these services, both authors have encountered new questions – potential variables – that can be brought back to the laboratory for further investigation. To illustrate, the first author recently worked a case in which the witness was given six simultaneous lineups, each with a different suspect, in order to identify two culprits. The witness chose four suspects out of the six lineups with varying degrees of confidence, even though there were only two culprits. This case raises many interesting questions. What effects do multiple lineups with multiple suspects have on the accuracy of the witness? How does the presence of two false identifications affect investigators', attorneys', and jurors' evaluations of the eyewitness? How 'should' these known false identifications affect evaluations of the eyewitness? Similarly, field studies and actual implementation of new lineup techniques can reveal questions and issues that have not been examined in the laboratory, thus suggesting new directions for laboratory research. With respect to the implications for justice, the application of eyewitness research to police practices and trials should serve to reduce identification errors and ultimately reduce the likelihood of erroneous conviction. Though much of the identification research seems to focus on one type of error (false identification), the research also has implications for improving the likelihood of correct identification and improving the extent to which positive identifications are diagnostic of guilt as well.

## References


Birnbaum IM and Parker ES (1977) *Alcohol and Human Memory*. Hillsdale, NJ: Lawrence Erlbaum.

Borchard E-M (1932) *Convicting the Innocent*. Garden City, NY: Garden City Publishing Company.

Bothwell RK, Brigham JC, and Deffenbacher KA (1987) Correlation of eyewitnesses accuracy and confidence: Optimality hypothesis revisited. *J. Appl. Psychol.* 72: 691–695.

Bradfield AL and Wells GL (2000) Post-identification feedback to eyewitness diminishes the certainty-accuracy relation. Presented at the Society for Applied Research in Memory and Cognition, Miami, FL, June.

Brewer N (2006) Uses and abuses of eyewitness identification confidence. *Legal Crim. Psychol.* 11: 3–23.

Brewer N, Weber N, and Semmler C (2005) Eyewitness identification. In: Brewer N and Williams KD (eds.) *Psychology and Law: An Empirical Perspective*, pp. 177–221. New York: Guilford.

Brigham JC (1993) College students' racial attitudes. *J. Appl. Soc. Psychol.* 23: 1933–1967.

Brigham JC and Cairns DL (1988) The effect of mugshot inspections on eyewitness identification accuracy. *J. Appl. Soc. Psychol.* 18(16, Pt 2): 1394–1410.

Brigham JC and Meissner CA (2000) Social and cognitive factors affecting the own-race bias in whites. *Basic Appl. Soc. Psychol.* 22: 71–84.

Brigham JC and Ready DL (1985) Own-race bias in lineup construction. *Law Hum. Behav.* 9: 415–424.

Brigham JC, Maass A, Martinez D, and Wittenberger G (1983) The effect of arousal on facial recognition. *Basic Appl. Soc. Psychol.* 4(3): 279–293.

Brown E, Deffenbacher K, and Sturgill W (1977) Memory for faces and the circumstances of encounter. *J. Appl. Psychol.* 62(3): 311–318.

Brown JM (2003) Eyewitness memory for arousing events: Putting things into context. *Appl. Cognit. Psychol.* 17: 93–106.

Carroo AW (1986) Other race recognition: A comparison of Black American and African subjects. *Percept. Mot. Skills* 62: 135–138.

Christianson S (1992) Emotional stress and eyewitness memory: A critical review. *Psychol. Bull.* 112(2): 284–309.

Christianson SA and Loftus EF (1991) Remembering emotional events: The fate of detail information. *Cogn. Emot.* 5: 81–108.

Clark S and Tunnicliff JL (2001) Selecting lineup foils in eyewitness identification experiments: Experimental control and real-world simulation. *Law Hum. Behav.* 25: 199–216.

Clark SE (1997) A familiarity-based account of confidence-accuracy inversions in recognition memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 23: 233–238.

Clark SE (2003) A memory and decision model for eyewitness identification. *Appl. Cogn. Psychol.* 17: 629–654.

Clark SE (2005) A re-examination of the effects of biased lineup instructions in eyewitness identification. *Law Hum. Behav.* 29: 395–342.

Clark SE and Davey SL (2005) The target-to-foils shift in simultaneous and sequential lineups. *Law Hum. Behav.* 29: 151–172.

Clifford BR and Hollin C (1981) Effects of the type of incident and the number of perpetrators on eyewitness memory. *J. Appl. Psychol.* 66: 364–370.

Cross JF, Cross J, and Daly J (1971) Sex, race, age, and beauty as factors in recognition of faces. *Percept. Psychophysiol.* 10: 393–396.

Cutler BL (2006) A sample of witness, crime, and perpetrator characteristics affecting eyewitness identification accuracy. *Cardozo Public Law Policy Ethics J.* 4: 327–340.

Cutler BL and Penrod SD (1988) Improving the reliability of eyewitness identification: Lineup construction and presentation. *J. Appl. Psychol.* 73(2): 281–290.

Cutler BL and Penrod SD (1989) Moderators of the confidence-accuracy correlation in face recognition: The role of information processing and base-rates. *Appl. Cogn. Psychol.* 3: 95–107.

Cutler BL and Penrod SD (1995) *Mistaken Identification: The Eyewitness, Psychology, and the Law*. Cambridge: Cambridge University Press.

Cutler BL, Penrod SD, O'Rourke TE, and Martens TK (1986) Unconfounding the effects of contextual cues on eyewitness identification accuracy. *Soc. Behav.* 1: 113–134.

Cutler BL, Penrod SD, and Martens TK (1987a) The reliability of eyewitness identification: The role of system and estimator variables. *Law Hum. Behav.* 11: 223–238.

Cutler BL, Penrod SD, and Martens TK (1987b) Improving the reliability of eyewitness identification: Putting context into context. *J. Appl. Psychol.* 72: 629–637.

Cutler BL, Penrod SD, and Dexter HR (1990) Juror sensitivity to eyewitness identification evidence. *Law Hum. Behav.* 14: 185–191.

Davies G, Ellis H, and Shepherd J (eds.) *Perceiving and Remembering Faces*. London: Academic Press.

Deffenbacher KA (1980) Eyewitnesses accuracy and confidence: Can we infer anything about their relationship? *Law Hum. Behav.* 4: 243–260.

Deffenbacher KA (1983) The influence of arousal on reliability of testimony. In: Lloyd-Bostock SMA and Clifford BR (eds) *Evaluating Witness Evidence*, pp. 235–251. New York: John Wiley and Sons Ltd.

Deffenbacher KA (1994) Effects of arousal on everyday memory. *Hum. Perform.* 7: 141–161.

Deffenbacher K and Horney J (1981) Psycho legal aspects of face identification. In: Davies G, Ellis H, and Shepherd J

(eds.) *Perceiving and Remembering Faces*, pp. 220–226. London: Academic Press.
Deffenbacher KA, Leu JR, and Brown EL (1981) Memory for faces: Testing method, encoding strategy, and confidence. *Am. J. Psychol.* 94: 13–26.
Deffenbacher KA, Bornstein BH, Penrod SD, and McGorty EK (2004) A meta-analytic review of the effects of high stress on eyewitness memory. *Law Hum. Behav.* 28: 687–706.
Deffenbacher KA, Bornstein BH, and Penrod SD (2006) Mugshot exposure effects: Retroactive interference, mugshot commitment, source confusion, and unconscious transference. *Law Hum. Behav.* 30: 287–307.
Devenport JL and Cutler BL (2004) Impact of defense-only and opposing eyewitness experts on juror judgments. *Law Hum. Behav.* 28: 569–576.
Dickenson JJ, Poole DL, and Laimon RL (2005) Children's recall and testimony. In: Brewer N and Williams Kipling D (eds.) *Psychology and Law: An Empirical Perspective*, pp. 11–42. New York NY: Guilford Press.
Doob AN and Kirshenbaum HM (1973) Bias in police lineups – partial remembering. *J. Police Sci. Admin.* 18: 287–293.
Douglass AB and Steblay NM (2006) Memory distortion in eyewitnesses: A meta-analysis of the post-identification feedback effect. *Appl. Cogn. Psychol.* 20: 859–870.
Douglass AB, Smith CA, and Fraser-Hill (2005) A problem with double-blind photospread procedures: Photospread administrators use one eyewitness's confidence to influence the identification of another witness. *Law Hum. Behav.* 29: 543–562.
Dunning D and Perretta S (2002) Automaticity and eyewitness accuracy: A 10 to 12 second rule for distinguishing accurate from inaccurate positive identifications. *J. Appl. Psychol.* 87: 951–962.
Dunning D and Stern LB (1994) Distinguishing accurate from inaccurate eyewitness identifications via inquiries about decision processes. *J. Pers. Soc. Psychol.* 67(5): 818–835.
Dysart JE, Lindsay RCL, Hammond R, and Dupuis P (2001) Mugshot exposure prior to lineup identification: Interference, transference, and commitment effects. *J. Appl. Psychol.* 86: 1280–1284.
Easterbrook JA (1959) The effect of emotion in cue utilization and the organization of behavior. *Psychol. Rev.* 66: 183–201.
Elliott R (1993) Expert testimony about eyewitness identification: A critique. *Law Hum. Behav.* 17: 423–437.
Ellis HD, Shepherd J, and Davies G (1975) An investigation of the use of Photo-fit technique for recalling faces. *Br. J. Psychol.* 66: 29–37.
Fein S, Hilton JL, and Miller DT (1990) Suspicion of ulterior motivation and the correspondence bias. *J. Pers. Soc. Psychol.* 58: 753–764.
Fein S, McCloskey AL, and Tomlinson TM (1997) Can the jury disregard that information? The use of suspicion to reduce the prejudicial effects of pretrial publicity and inadmissible testimony. *Pers. Soc. Psychol. Bull.* 23: 1215–1226.
Fisher RP and Geiselman RE (1992) *Memory-Enhancing Techniques for Investigative Interviewing*. Springfield, IL: C. Charles Thomas.
Fisher RP, Geiselman RE, and Amador M (1989) Field test of the cognitive interview: Enhancing the recollection of actual victims and witnesses of crime. *J. Appl. Psychol.* 74: 722–727.
Fisher RP and Schieber N (2006) Interviewing protocols for improving eyewitness memory. In: Toglia MP, Read D, Ross DF, and Lindsay RCL (eds.) *Handbook of Eyewitness Psychology, Vol. 1: Memory for People*, pp. 53–80. Mahwah, NJ: Erlbaum.
Fox SG and Walters HA (1986) The impact of general versus specific expert testimony and eyewitness confidence upon mock juror judgment. *Law Hum. Behav.* 10: 215–228.
Garrioch L and Brimacombe CAE (2001) Lineup administrators' expectations: Their impact on eyewitness confidence. *Law Hum. Behav.* 25: 299–315.
Geiselman RE and Machlovitz H (1987) Hypnosis memory recall: Implications for forensic use. *Am. J. Forensic Psychol.* 5: 37–47.
Gibson JJ (1969) *Principles of Perceptual Learning and Development*. New York: Appleton-Century-Crofts.
Gonzalez R, Ellsworth PC, and Pembroke M (1993) Response biases in lineups and showups. *J. Pers. Soc. Psychol.* 64(4): 525–537.
Gorenstein GW and Ellsworth PC (1980) Effect of choosing an incorrect photograph on a later identification by an eyewitness. *J. Appl. Psychol.* 65: 616–622.
Hafstad GS, Memon A, and Logie R (2004) Postidentification feedback, confidence and recollections of witnessing conditions in child witnesses. *Appl. Cogn. Psychol.* 18: 901–912.
Haw RM and Fisher RP (1989) Effects of administrator-witness contact on eyewitness identification accuracy. *J. Appl. Psychol.* 6: 1106–1112.
Haw RM and Fisher RP (2004) Effects of administrator-witness contact on eyewitness identification accuracy. *J. Appl. Psychol.* 89: 1106–1112.
Hinz T and Pezdek K (2001) The effect of exposure to multiple lineups on face identification accuracy. *Law Hum. Behav.* 25: 185–198.
Hockley WE, Hemsworth DH, and Consoli A (1999) Shades of the mirror effect: Recognition of faces with and without sunglasses. *Mem. Cogn.* 27: 128–138.
Huff R, Rattner A, and Sagarin E (1996) *Convicted but Innocent*. Thousand Oaks, CA: Sage.
Hunt RR and Ellis HC (1974) Recognition memory and degree of semantic contextual change. *J. Exp. Psychol.* 103(6): 1153–1159.
Junkin T and Bloodsworth K (2004) *Bloodsworth: The True Story of the First Death Row Inmate Exonerated by DNA*. New York: Workman Publishing.
Karlin RA and Orne MT (1996) Commentary on Borawick v. Shay: Hypnosis, social influence, incestuous child abuse, and Satanic ritual abuse: The iatrogenic creation of horrific memories for the remote past. *Cultic Stud J.* 13: 42–94.
Kassin SM (1985) Eyewitness identification: Retrospective self-awareness and the accuracy-confidence correlation. *J. Pers. Soc. Psychol.* 49: 878–893.
Kassin SM, Ellsworth PC, and Smith VL (1989) The ''general accepance'' of psychological research on eyewitness testimony: A survey of the experts. *Am. Psychol.* 44(8): 1089–1098.
Kassin SM, Tubb VA, Hosch HM, and Memon A (2001) On the ''general acceptance'' of eyewitness testimony research. *Am. Psychol.* 56: 405–416.
Kebbell MR, Wagstaff GF, and Covey JA (1996) The influence of item difficulty on the relationship between eyewitness confidence and accuracy. *Br. J. Psychol.* 87: 653–662.
Kneller W, Memon A, and Stevenage S (2001) Simultaneous and sequential lineups: Decision processes of accurate and inaccurate eyewitnesses. *Appl. Cogn. Psychol.* 15: 659–671.
Konecni VJ and Ebbesen EB (1986) Courtroom testimony by psychologists on eyewitness identification issues: Critical notes and reflections. *Law Hum. Behav.* 10(1–2): 117–126.
Kramer TH, Buckhout R, and Eugenio P (1990) Weapon focus, arousal, and eyewitness memory: Attention must be paid. *Law Hum. Behav.* 14(2): 167–184.
Leippe MR (1995) The case for expert testimony about eyewitness memory. *Psychol. Public Policy Law* 1: 909–959.
Lieppe MR, Wells GL, and Ostrom TM (1978) Crime seriousness as a determinant of accuracy in eyewitness identification. *J. Appl. Psychol.* 63: 345–351.

Leippe MR, Eisenstadt D, Rauch SM, and Seib JM (2004) Timing of eyewitness expert testimony, jurors' need for cognition, and case strength as determinants of trial verdicts. *J. Appl. Psychol.* 89: 524–541.
Leippe MR, Eisenstadt D, Rauch SM, and Stambush M (2006) Effects of social-comparative memory feedback on eyewitnesses' identification confidence, suggestibility, and retrospective memory reports. *Basic Appl. Soc. Psychol.* 28: 201–220.
Lindsay DS (1991) CHARMed, but not convinced: Comment on Metcalfe (1990). *J. Exp. Psychol. Gen.* 120: 101–105.
Lindsay DS, Jack PC, and Christian MA (1991) Other-race face perception. *J. Appl. Psychol.* 76: 587–589.
Lindsay RCL and Wells GL (1985) Improving eyewitness identification from lineups: Simultaneous versus sequential lineup presentations. *J. Appl. Psychol.* 70: 556–564.
Lindsay RCL, Martin R, and Webber L (1994) Default values in eyewitness descriptions: A problem for the match-to-description lineup foil selection strategy. *Law Hum. Behav.* 18(5): 527–541.
Lindsay RCL, Pozzulo JD, Craig W, Lee K, and Corber S (1997) Simultaneous lineups, sequential lineups, and showups: Eyewitness identification decisions of adults and children. *Law Hum. Behav.* 21: 391–404.
Loftus EF (1996) *Eyewitness Testimony*, 2nd edn. Cambridge, MA: Harvard University Press.
Loftus EF, Miller DG, and Burns HJ (1978) Semantic integration of verbal information into a visual memory. *J. Exp. Psychol. Hum. Learn. Mem.* 4: 19–31.
Loftus EF, Loftus GR, and Messo J (1987) Some facts about "weapon focus." *Law Hum. Behav.* 11(1): 55–62.
Luce TS (1974) The role of experience in inter-racial recognition. *Pers. Soc. Psychol. Bull.* 1(1): 39–41.
Luus CAE and Wells GL (1991) Eyewitness identification and the selection of distractors for lineups. *Law Hum. Behav.* 15: 43–57.
Luus CAE and Wells GL (1994) The malleability of eyewitness confidence: Co-witness and perseverance effects. *J. Appl. Psychol.* 79: 714–723.
Lynn SJ, Lock TG, Myers B, and Payne DG (1997) Recalling the unrecallable: Should hypnosis be used to recover memories in psychotherapy? *Curr. Dir. Psychol. Sci.* 6(3): 79–83.
Maclin OH, Maclin MK, and Malpass RS (2001) Race arousal attention, exposure, and delay: An examination of factors moderating face recognition. *Psychol. Public Pol. Law* 7: 134–152.
MacLin OH, Zimmerman LA, and Malpass RS (2005) PC eyewitness and the sequential superiority effect: Computer based lineup administration. *Law Hum. Behav.* 29: 303–321.
Malpass RS (1981a) Effective size and defendant bias in eyewitness identification lineups. *Law Hum. Behav.* 5(4): 299–309.
Malpass RS (1981b) Training in face recognition. In: Davies G, Ellis H, and Shepherd J (eds.) *Perceiving and Remembering Faces*, pp. 271–285. London: Academic Press.
Malpass RS (1990) An excursion into utilitarian analysis. *Behav. Sci. Res.* 24: 1–15.
Malpass RS and Devine PG (1981a) Eyewitness identification: Lineup instructions and the absence of the offender. *J. Appl. Psychol.* 66: 482–489.
Malpass RS and Devine PG (1981b) Guided memory in eyewitness identification. *J. Appl. Psychol.* 66: 343–350.
Malpass RS and Devine PG (1983) Measuring the fairness of eyewitness identification in lineups. In: Lloyd-Bostock S and Clifford B (eds.) *Evaluating Eyewitness Evidence*, pp. 81–102. London: John Wiley and Sons Ltd.
Manson v. Braithwaite, 432 US 98 (1977)
McQuiston-Surrett DE, Malpass RS, and Tredoux CG (2006) Sequential vs. simultaneous lineups: A review of methods data, and theory. *Psychol. Public Pol. Law* 12: 137–169.
Meissner CA and Brigham JC (2001a) Thirty years of investigating the own race bias in memory for faces: A meta-analytic review. *Psychol. Public Pol. Law* 7: 3–35.
Meissner CA and Brigham JC (2001b) A meta-analysis of the verbal overshadowing effect in face identification. *Appl. Cogn. Psychol.* 15(6): 603–616.
Meissner CA, Sporer S, and Schooler J (2007) Person descriptions as eyewitness evidence. In: Toglia MP, Read D, Ross DF, and Lindsay RCL (eds.) *Handbook of Eyewitness Psychology, Vol. 1: Memory for People*, pp. 3–34. Mahwah, NJ: Erlbaum.
Meissner CA, Tredoux CG, Parker JF, and Maclin OH (2005) Eyewitness decisions in simultaneous and sequential lineups: A dual-process signal detection theory analysis. *Mem. Cogn.* 33: 783–792.
Memon A and Gabbert F (2003) Improving the identification accuracy of senior witnesses: Do pre-lineup questions and sequential testing help? *J. Appl. Psychol.* 88: 341–347.
Memon A, Hope L, and Bull R (2003) Exposure duration: Effects on eyewitness accuracy and confidence. *Br. J. Psychol.* 94: 339–354.
Mitchell KJ, Livosky M, and Mather M (1998) The weapon focus effect revisited: The role of novelty. *Legal Criminol. Psychol.* 3: 287–303.
Morgan CA III, Hazlett G, Doran A, et al. (2004) Accuracy of eyewitness memory for persons encountered during exposure to highly intense stress. *Int. J. Law Psychiatry* 27(3): 265–279.
Mueller-Johnson K and Ceci SJ (2004) Memory and suggestibility in older adults: Live event participation and repeated interview. *Appl. Cogn. Psychol.* 18: 1109–1128.
Navon D (1992) Selection of lineup foils by similarity to suspect is likely to misfire. *Law Hum. Behav.* 16: 575–593.
Nisbett RE and Wilson TD (1977) Telling more than we can know: Verbal reports on mental processes. *Psychol. Rev.* 84: 231–259.
Neil v. Biggers, 409 US 188 (1972)
Neuschatz JS, Preston EL, Burkett AD, et al. (2005) The effects of post-identification feedback and age on retrospective eyewitness memory. *Appl. Cogn. Psychol.* 19: 435–453.
Neuschatz JS, Neuschatz JS, Lawson DS, et al. (2007) The mitigating effects of suspicion on post-identification feedback and on retrospective eyewitness memory. *Law Hum. Behav.* 31: 231–247.
O'Rourke TE, Penrod SD, Cutler BL, and Stuve TE (1989) The external validity of eyewitness identification research: Generalizing across subject populations. *Law Hum. Behav.* 13: 385–395.
Penrod S and Cutler B (1995) Witness confidence and witness accuracy: Assessing their forensic relation. *Psychol. Public Pol. Law* 1: 817–845.
Phillips MR, McAuliff BD, Kovera MB, and Cutler BL (1999) Double-blind photo array administration as a safeguard against investigator bias. *J. Appl. Psychol.* 84(6): 940–951.
Pickel KL (1998) Unusualness and threat as possible causes of "weapon focus." *Memory* 6(3): 277–295.
Pickel KL (1999) The influence of context on the "weapon focus" effect. *Law Hum. Behav.* 23(3): 299–311.
Platz SJ and Hosch HM (1988) Cross-racial/ethnic eyewitness identification: A field study. *J. Appl. Soc. Psychol.* 18: 972–984.
Powell MB, Fisher RP, and Wright R (2005) Investigative interviewing. In: Brewer N and Williams Kipling D (eds.) *Psychology and Law: An Empirical Perspective*, pp. 11–42. New York: Guilford Press.

Pozzulo J and Lindsay R (1998) Identification accuracy of children versus adults: A meta-analysis. *Law Hum. Behav.* 22: 549–570.
Rattner A (1988) Convicted but innocent: Wrongful conviction and the criminal justice system. *Law Hum. Behav.* 12(3): 283–293.
Read JD (1995) The availability heuristic in person identification: The sometimes misleading consequences of enhanced contextual information. *Appl. Cogn. Psychol.* 9: 91–122.
Read JD, Hammersley R, Cross-Calvert S, and McFadzen E (1989) Rehearsal od faces and details in action events. *Appl. Cogn. Psychol.* 3: 295–311.
Read JD, Tollestrup P, Hammersley R, McFadzen E, and Christensen A (1990a) The unconscious transference effect: Are innocent bystanders ever misidentified? *Appl. Cogn. Psychol.* 4: 3–31.
Read JD, Vokey JR, and Hammersley R (1990b) Changing photos of faces: Effects of exposure duration and photo similarity on recognition and the accuracy-confidence relationship. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 870–882.
Reisberg D, Heuer F, McLean J, and O'Shaughnessy M (1988) The quantity, not the quality, of affect predicts memory vividness. *Bull. Psychon. Soc.* 26: 100–103.
Robinson MD and Johnson JT (1996) Recall memory recognition memory, and the eyewitness confidence-accuracy correlation. *J. Appl. Psychol.* 81: 587–594.
Rosenthal R and Jacobson L (1968) *Pygmalion in the Classroom*. New York: Holt Rinehart and Winston.
Ross DF, Dunning D, Toglia MP, and Ceci SJ (1990) The child in the eyes of the jury. *Law Hum. Behav.* 14: 5–23.
Russano MB, Dickinson JJ, Greathouse SM, and Kovera MB (2006) ''Why don't you take another look at number three?'' Investigator knowledge and its effects on eyewitness confidence and identification decisions. *Cardozo Public Law Policy Ethics J.* 4: 355–379.
Schooler JW and Engstler-Schooler TY (1990) Verbal overshadowing of visible memories: Some things are better left unsaid. *Cogn. Psychol.* 22: 36–71.
Scheck B, Neufeld P, and Dwyer J (2000) *Actual Innocence*. New York: Doubleday.
Scheflin AW, Spiegel H, and Spiegel D (1999) Forensic uses of hypnosis. In: Hess AK and Weiner IB (eds.) *The Handbook of Forensic Psychology,* 2nd edn, pp. 474–498. New York: John Wiley.
Schmechel RS, O'Toole TP, Easterly C, and Loftus EF (2006) Beyond the ken: Testing jurors' understanding of eyewitness reliability evidence. *Jurimetrics J.* 46: 177–214.
Schooler JW, Foster RA, and Loftus EF (1988) Some deleterious consequences of the act of recollection. *Mem. Cogn.* 16: 243–251.
Shapiro P and Penrod SD (1986) A meta-analysis of the facial identification literature. *Psychol. Bull.* 100: 139–156.
Shepherd J (1983) Identification after long delays. In: Lloyd-Bostock SMA and Clifford BR (eds.) *Evaluating Witness Evidence*, pp. 173–187. New York: Wiley.
Slone AE, Brigham JC, and Meissner CA (2000) Social and cognitive factors affecting the own-race bias in Whites. *Basic Appl. Soc. Psychol.* 22: 71–84.
Smith SM, Lindsay RCL, and Pryke S (2000) Postdictors of eyewitness errors: Can false identifications be diagnosed? *J. Appl. Psychol.* 85(4): 542–550.
Smith SM, Lindsay RCL, Pryke S, and Dysart JE (2001) Postdictors of eyewitness errors: Can false identifications be diagnosed in the cross-race situation? *Psychol. Public Policy Law* 7: 153–169.
Sporer SL (1993) Eyewitness identification accuracy, confidence, and decision times in simlutaneous and sequential lineups. *J. Appl. Psychol.* 78: 22–33.
Sporer SL, Penrod S, Read D, and Cutler B (1995) Choosing, confidence, and accuracy; A meta-analysis of the confidence-accuracy relation in eyewitness identification studies. *Psychol. Bull.* 118(3): 315–327.
Steblay NM (1992) A meta-analytic review of the weapon focus effect. *Law Hum. Behav.* 16: 413–424.
Steblay NM (1997) Social influences in eyewitness recall: A meta-analytic review of lineup instruction effects. *Law Hum. Behav.* 21(3): 283–297.
Steblay NM, Dysart J, Fulero S, and Lindsay RCL (2001) Eyewitness accuracy rates in sequential and simultaneous line-up presentations: A meta-analytic comparison. *Law Hum. Behav.* 25: 459–474.
Steblay NM, Dysart J, Fulero S, and Lindsay RCL (2003) Eyewitness accuracy rates in police showup and lineup presentations: A meta-analytic comparison. *Law Hum. Behav.* 27: 523–540.
Technical Working Group on Eyewitness Evidence (1999) *Eyewitness Evidence: A Guide for Law Enforcement*. Washington, DC: US Department of Justice. http://www.ojp.usdoj.gov/nij/pubs-sum/178240.htm (accessed 6 June 2007).
Thompson CP, Herrmann DJ, Bruce D, Read JD, Payne DG, and Toglia MP (1998) *Autobiographical Memory: Theoretical and Applied Perspectives*. Mahwah, NJ: Lawrence Erlbaum Associates.
Transcript of Jennifer Thompson Cannino's speech (2006) *Cardozo Public Law Pol. Ethics J.* 4: 251–264.
Transcript of Penny Beersten's speech (2006) *Cardozo Public Law Policy Ethics J.* 4: 239–249.
Tulving E (1983) *Elements of Episodic Information*. Oxford: Oxford University Press.
United States v. Ramirez-Rodriguez, 552 F2d 883: 884 (9th Cir. 1977).
Valentine T, Pickering A, and Darling S (2003) Characteristics of eyewitness identification that predict the outcome of real line-ups. *Appl. Cogn. Psychol.* 17: 969–993.
Van Wallendael LR, Devenport JL, Cutler BL, and Penrod SD (2007) Mistaken identification = erroneous convictions? assessing and improving legal safeguards. In: Lindsay RCL, Ross DF, Read JD, and Toglia MP (eds.) *Handbook of Eyewitness Testimony,* vol. 2, pp. 557–572. Mahwah, NJ: Erlbaum.
Vokey JR and Read JD (1992) Familiarity, memorability and the effect of typicality on the recognition of faces. *Mem. Cogn.* 20: 291–302.
Wagenaar WA and Groeneweg J (1990) The memory of concentration camp survivors. *Appl. Cogn. Psychol.* 4: 77–87.
Weber N, Brewer N, Wells GL, Semmler C, and Keast A (2004) Eyewitness identification accuracy and response latency: The unruly 10–12 second rule. *J. Exp. Psychol. Appl.* 10: 139–147.
Wells GL (1978) Applied eyewitness-testimony research: System variables and estimator variables. *J. Pers. Soc. Psychol.* 36(12): 1546–1557.
Wells GL (1984) The psychology of lineup identifications. *J. Appl. Soc. Psychol.* 14: 89–103.
Wells GL (1993) What do we know about eyewitness identification? *Am. Psychol.* 48(5): 553–571.
Wells GL (2000) Eyewitness testimony. In: Kazdin AE (ed.) *Encyclopedia of Psychology*. Washington, DC: American Psychological Association.
Wells GL and Bradfield AL (1998) ''Good, you identified the suspect'': Feedback to eyewitnesses distorts their reports of the witnessing experience. *J. Appl. Psychol.* 83: 360–376.
Wells GL and Bradfield AL (1999) Distortions in eyewitnesses' recollections: Can the postidentification feedback effect be moderated? *Psychol. Sci.* 10: 138–144.

Wells GL and Hryciw B (1984) Memory for faces: Encoding and retrieval operations. *Mem. Cogn.* 12: 338–344.
Wells GL and Luus CA E (1990) The diagnosticity of a lineup should not be confused with the diagnostic value of nonlineup evidence. *J. Appl. Psychol.* 75(5): 511–516.
Wells GL and Murray DM (1984) Eyewitness confidence. In: Wells GL and Loftus EF (eds.) *Eyewitness Testimony: Psychological Perspectives*, pp. 155–170. New York: Cambridge University Press.
Wells GL and Olson E (2003) Eyewitness identification. *Annu. Rev. Psychol.* 54: 277–295.
Wells GL, Lindsay RCL, and Ferguson TJ (1979) Accuracy, confidence, and juror perceptions in eyewitness identifications. *J. Appl. Psychol.* 64: 440–448.
Wells GL, Ferguson TJ, and Lindsay RCL (1981) The tractability of eyewitness confidence and its implication for triers of fact. *J. Appl. Psychol.* 66: 688–696.
Wells GL, Rydell SM, and Seelau EP (1993) On the selection of distracters for eyewitness lineups. *J. Appl. Psychol.* 78: 835–844.
Wells GL, Seelau EP, Rydell SM, and Luus CAE (1994) Recommendations for properly conducted lineup identification tasks. In: Ross DF, Read JD, and Toglia MP (eds.) *Adult Eyewitness Testimony: Current Trends and Developments*, pp. 223–244. New York: Cambridge University Press.
Wells GL, Small M, Penrod S, Malpass RS, Fulero SM, and Brimacombe CAE (1998) Eyewitness identification procedures: Recommendations for lineups and photospreads. *Law Hum. Behav.* 23(6): 603–647.
Wells GL, Olson EA, and Charman SD (2003) Distorted retrospective eyewitness reports as functions of feedback and delay. *J. Exp. Psychol. Appl.* 9: 42–52.
Yarmey AD, Yarmey AL, and Yarmey MJ (1994) Face and voice identifications in showups and lineups. *Appl. Cogn. Psychol.* 8: 453–464.
Yarmey AD, Yarmey MJ, and Yarmey AL (1996) Accuracy of eyewitness identifications in showups and lineups. *Law Hum. Behav.* 20(4): 459–477.
Yerkes RM and Dodson JD (1908) The relation of strength of stimulus to rapidity of habit formation. *J. Comp. Neurol. Psychol.* 18: 459–482.
Yuille JC and Cutshall JL (1986) A case study of eyewitness memory of a crime. *J. Appl. Psychol.* 71: 291–301.
Yuille JC and Tollestrup PA (1992) A model of the diverse effects of emotion on eyewitness memory. In: Cristianson SA (ed.) *The Handbook of Emotion and Memory: Research and Theory*, pp. 144–160. Hillsdale, NJ: Erlbaum.

# 2.45 Prospective Memory: Processes, Lifespan Changes, and Neuroscience

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Prospective memory involves remembering to perform actions in the future. Thus, remembering to buy a loaf of bread on the way home, remembering to go to the dentist for an appointment, and remembering to actually attach an attachment to an email all are examples of prospective memory. Prospective memory has often been contrasted with retrospective memory (we explore this distinction in more detail in a subsequent section), which is what is typically studied in the laboratory. Remembering the plot of a movie that you saw 2 weeks ago and remembering a list of words presented in an experiment are examples of retrospective memory.

## 2.45.1 The Importance of Prospective Memory in Everyday Life

An interesting feature of prospective memory is that it is prevalent in everyday life and central to normal functioning, and yet it is an area that until recently has been neglected by memory researchers. In reflecting on the activities in our typical day, it is easy to realize the enormous number of prospective memory demands that permeate our lives. From remembering to take vitamins and medication in the morning to remembering meetings, appointments, and errands throughout the day, our lives are full of prospective memory demands. Consistent with this impression that prospective memory demands are ubiquitous, Crovitz and Daniel (1984), in a study in which they asked students to record in a diary all instances of forgetting over a 1-week period, found that about half of the reported instances of forgetting were prospective in nature.

Not only do prospective memory demands permeate our lives, but successful remembering is also critical to normal and efficient functioning. Consider that one-third of older adults take three or more medications on a regular basis (Morell et al., 1997). Problems in remembering to take these medications could have serious health consequences and could threaten independent living. Consider also that prospective memory demands are often the cause of mistakes and accidents at work (Reason, 1990). Indeed, Nowinski et al. (2003), in examining voluntary reports of cockpit incidents from pilots to the Aviation Safety Reporting System, found that 74 of the 75 memory failures in their sample were prospective in nature. From the other side of airline safety, imagine the consequences of prospective memory failure for a busy air traffic controller, who gets the thought to reroute an airplane but cannot do so immediately because she is engaged in another activity and therefore must hold on to the intention until she is free. As another example, despite the best intentions of conscientious surgical teams, roughly once a year in a large hospital, they accidentally leave foreign instruments such as sponges and clamps in a patient. The patient shown in **Figure 1** complained of abdominal pain and nausea 8 months after a hernia surgery. As you can see, a scan revealed that the surgical team had forgotten to remove a 16-cm clamp from his abdominal area.

More generally, Tulving (2004) theorizes that a forward-looking mind that is capable of imagining and anticipating the future is critical to human survival. He assumes that this subjective and conscious apprehension of the future is mediated by the episodic memory system, and he labels this ability proscopic chronesthesia. Moreover, he believes that this ability is unique to humans and that the evolution of this ability was necessary for the creation of human culture. Prospective memory is among the important functions of chronesthetic consciousness. The idea here is that basic survival as well as rich human-like social relationships benefit from those who are capable of appreciating the future, planning for it, and later remembering to perform planned actions.

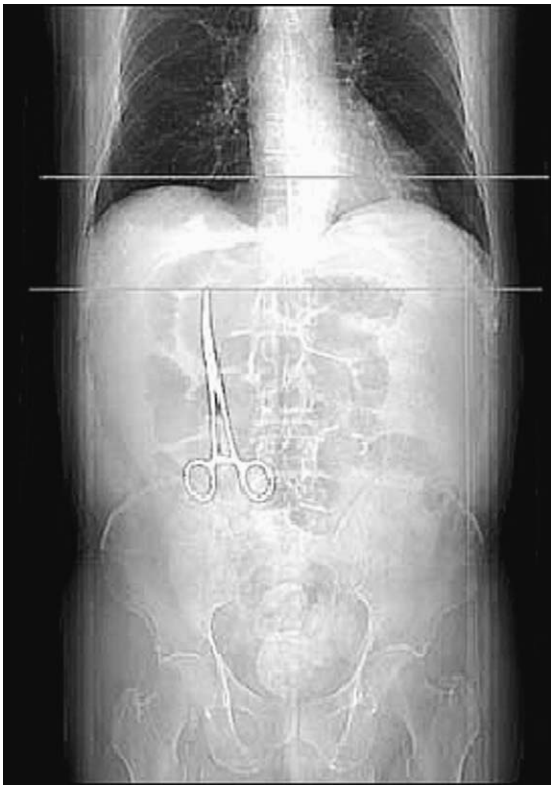

**Figure 1** Scan showing a 16-cm clamp left in the abdominal area of a patient. From Dembitzer A and Lai EJ (2003) Retained surgical instrument. *N. Engl. J. Med.* 348–228.

In the 1980s, a few researchers (e.g., Harris, 1984; Craik, 1986) started proposing that the retrospective memory literature had not addressed fundamental issues in prospective memory and, as such, alerted researchers to the gap in our understanding of prospective memory. As can be seen in **Figure 2**, the number of articles and chapters on prospective memory (collapsed over 2-year intervals) has risen dramatically since that time. The increased interest has been driven by a number of factors, including the realization that prospective remembering is critical to our everyday leisure and work lives, the growing awareness that important components of prospective memory tend not to be studied in the typical retrospective memory experiment or captured in conventional neuropsychological assessments of memory, the development of laboratory paradigms for studying prospective

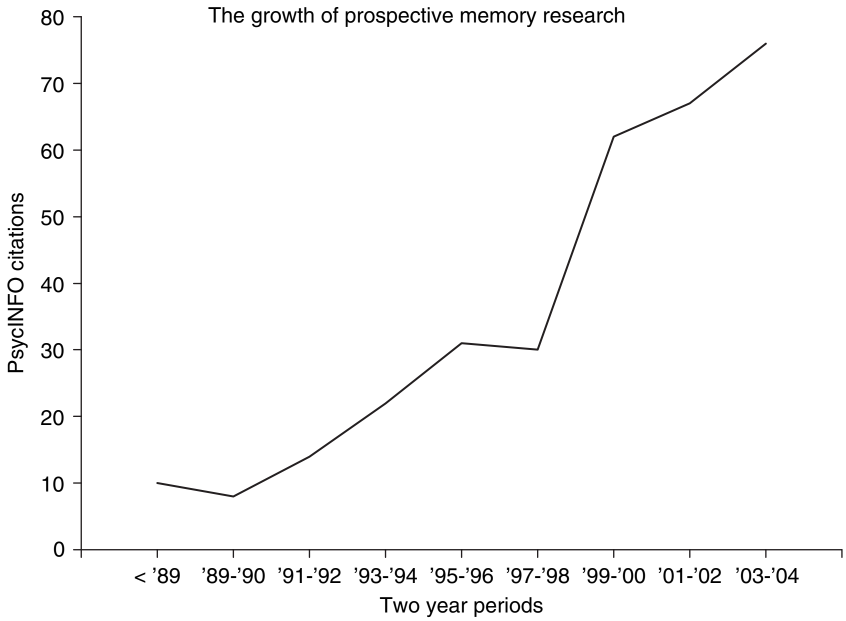


**Figure 2** References to prospective memory over recent years in the PsychINFO database. From Marsh RL, Cook GI, and Hicks JL (2006a) An analysis of prospective memory. In: Ross BH (ed.) *The Psychology of Learning and Motivation*, Vol. 46, pp. 115–153. San Diego: Academic Press.

memory, theoretical progress on the cognitive processes that support prospective memory as well as interest in how these processes change across the lifespan, and the development of imaging techniques for understanding the neural basis of prospective memory. We focus on these factors in this chapter.

## 2.45.2 Paradigms for Studying Prospective Memory

By and large, explicit retrospective memory tasks involve presenting people with materials to learn and then, at some later point, putting the participants in what Tulving (1983) calls a retrieval mode and directing them to search memory for the previously learned information. For example, in the standard cued recall task, participants might be asked to learn pairs of items (e.g., dog/grass, table/binder, etc.). After a delay, the experimenter presents the first member of the pair and explicitly asks the participants to search memory for the associated second member of each pair. On the surface, many prospective memory tasks resemble this cued-recall scenario. Consider, for example, remembering to give your friend Patty a message. It is likely that you form an association between Patty and the message (i.e., Patty/message), and then after a delay, when Patty occurs, you need to retrieve the message. A major difference between this and the retrospective cued recall task, however, is that in the prospective memory task no one puts the participant in a retrieval mode and asks her or him to search memory when the target cue occurs (i.e., Patty). Instead, upon seeing Patty, successful remembering requires that the participant remember to retrieve the intention on her or his own. It is this feature of prospective memory that led Craik (1986) to characterize prospective memory as being especially high in self-initiated retrieval. Thus, in designing a research paradigm for studying prospective memory, it is critical to include this self-initiated component of requiring subjects to remember on their own (see McDaniel and Einstein, 2007, Chapter 1, for additional defining features of prospective memory tasks).

### 2.45.2.1 Nonlaboratory Paradigms

The earliest methods for investigating prospective memory were conducted outside of the laboratory. For example, Meacham and Singer (1977) asked college students to return postcards on specified days and found, among other results, that stronger incentives led to better prospective memory. Other studies (West, 1988; Maylor, 1990) asked subjects to telephone the experimenter at particular times. Another approach is to examine the success with which people remember to carry out their own intentions. For example, Marsh et al. (1998b) asked subjects to list their planned activities for the next week (along with the importance of each). One week later, they asked them to indicate which intentions had been carried out and which had not (and to try to explain why these were not performed). In the medication adherence literature, researchers have asked people to adhere to their medication regimen and then put their pills in electronic medication bottles that record the date and time (over a 6-month period) every time the bottle cap is removed (see Park and Kidder, 1996, for a description). As reflected in these studies, nonlaboratory paradigms have the potential to examine prospective memory under highly naturalistic conditions.

One limitation of this approach, however, is that it is difficult to assess and/or control the strategies that subjects use in particular situations. For example, in the Meacham and Singer (1977) postcard study, some of the student subjects may have remembered using purely cognitive strategies, others may have used calendars, and still others may have given the post-cards to their parents to return for them. Thus, it is difficult to hone in on the mechanism by which incentives improve prospective remembering. Imagine also comparing older and younger adults and finding that the older adults remember more often than the younger adults (a typical finding in naturalistic studies; see Henry et al., 2004). This type of paradigm does not allow you to determine whether the better prospective memory for older adults was a result of more effective cognitive processes related to prospective memory, greater use of external aids, or both.

In recent years, researchers have been creative in elaborating nonlaboratory paradigms, and this has enabled them to begin exploring these processes. Kvavilashvili and Fisher (2007), for example, asked subjects to remember to call the experimenter 1 week later. They additionally asked them to record in a diary all thoughts related to the prospective memory intention over the 1-week period. Among other findings, Kvavilashvili and Fisher found that related cues (such as walking past a telephone pole) tended to spontaneously trigger thoughts of the intention. Sellen et al. (1997) gave their participants, all of whom were employees working in a single building, a prospective memory intention to perform for several days (e.g., to perform an action whenever they were in a particular room in the building). Moreover, the participants wore badges and were instructed to click their badge whenever they thought of the intention. There were sensors in the building that enabled the researchers to determine the location of the badge when it was clicked. Interestingly, participants were more likely to think of their intention when they were in transition (e.g., walking from one room to another) than when they were settled in a particular room (i.e., engaged by a task). Although these nonlaboratory paradigms have advantages over laboratory techniques in the sense that they tend to more closely approximate real-world prospective memory demands, ultimately they do not allow the precise control over independent and extraneous variables that is afforded by laboratory techniques. We now outline the basic laboratory paradigm that has been used.

### 2.45.2.2 Laboratory Paradigms

The essence of laboratory tests of prospective memory has been to busily engage participants in an ongoing task and to give them an intention to perform at some later time (see **Table 1** for the major

**Table 1** A typical laboratory paradigm for studying prospective memory

| | |
|---|---|
| 1 | Present participants with instructions and practice trials for an ongoing task (e.g., pleasantness rating). |
| 2 | Present participants with the prospective memory (PM) instructions (e.g., press a designated key whenever you see the word 'rake' in the context of the ongoing task). |
| 3 | A delay is introduced during which participants perform other activities (e.g., do other memory tasks and/or fill out demographics forms). |
| 4 | Reintroduce the ongoing task (pleasantness rating) without reminding participants of the PM task. |
| 5 | The PM target ('rake') occurs several times in the ongoing task, and PM performance is measured by the proportion of times participants remember to press the designated key when the target occurs. |
| 6 | To verify that forgetting was a result of PM failure rather than retrospective memory failure, participants are queried at the end of the experiment for their memory of the task demands. |

From Einstein GO and McDaniel MA (2005) Prospective memory: Multiple retrieval processes. *Curr. Dir. Psychol. Sci.* 14: 286–290.

phases of a typical experiment, and see Einstein and McDaniel, 1990, for a specific example). Successful prospective memory requires that one remembers to perform an intended action (the prospective component) and also the contents of the intention (i.e., that the target item is 'rake' and the particular response key to press; the retrospective component). In explicit retrospective memory tasks, experimenters challenge the retrospective component. That is, they present participants with a body of material and then test how much is retained. In prospective memory tasks, the retrospective content is usually kept simple, and the question is whether participants will remember to perform the action at the appropriate moment or time period. This is done so that one can be fairly certain that omissions are the result of prospective memory failures as opposed to forgetting the contents of the intention. Indeed, it is important to verify this by testing participants at the end of the experiment for their memory of the prospective memory task demands. Prospective memory failures occur when participants fail to perform the intended action and yet later show complete memory for the task demands (i.e., the retrospective component).

This basic paradigm seems to capture the processes that are involved in many everyday prospective memory demands. For example, consider the prospective memory task described earlier: the task of remembering to give your friend Patty a message. After forming the intention, there is a delay during which we become engaged by the demands of life (i.e., the ongoing task), and the interest is in whether we will remember to give the message when we later see Patty (i.e., the prospective memory target). Within this general paradigm, researchers have manipulated a number of variables, including the emphasis on the ongoing and prospective memory task (Marsh et al., 2005), whether the cue for initiating the action is an event, a time, or an activity (e.g., Einstein et al., 1995), the nature of the cue (e.g., whether the cue is distinctive; McDaniel and Einstein, 1993), the length of the delay (e.g., Hicks et al., 2000), and the demands on the participant while encoding the intention and at the point of retrieval (e.g., Einstein et al., 1997; Marsh and Hicks, 1998).

Despite the widespread use of some variation of this basic laboratory paradigm, it is important to realize that it does not capture all real-world prospective memory processes. For example, planning is minimized as the experimenter tells the subject when to perform the action. Also, Dismukes (2007) points out that many everyday prospective memory demands, unlike those in laboratory tasks, are embedded in well-learned and highly sequenced routines. For instance, a pilot's typical sequence of actions prior to take off may be to perform a checklist of actions, then set the flaps to take-off position, and then taxi to the runway. For an experienced pilot, this sequence has been performed thousands of times in just this order, and the completion of the checklist and the perceptual environment prior to taxiing are strong cues for setting the flaps to the take-off position. There has been little research examining this kind of heavily cued habitual prospective memory task or what happens on those rare occasions when the action must be performed out of sequence (e.g., when weather conditions require that the pilot delay the setting of the flaps until after taxiing, when the normal kinesthetic and perceptual cues are no longer present). In theory, however, these kinds of conditions can be created in the laboratory either through training or by taking advantage of long-standing habits. Thus, while it is clear that existing tasks have been and continue to be useful for understanding basic processes involved in the encoding, storage, and retrieval of prospective memories, we look forward to the development of other laboratory paradigms for examining prospective memory under a broader set of conditions.

## 2.45.3 Varieties of Prospective Memory Tasks and How They Are Measured

### 2.45.3.1 Event-Based Prospective Memory

Although there are some grey areas when defining prospective memory tasks (see McDaniel and Einstein, 2007, Chapter 1), the field seems to have focused the research on three main types of tasks. The lion's share of the research has examined event-based prospective memory in which the rememberer offloads the intention onto some external environmental cue or cues. An example of an event-based task is the one described in the previous section of pressing a key when the target word 'rake' is encountered while performing an ongoing task. A real-world example would be the task of stopping to buy stamps when driving by the post office. Usually performance on an event-based task is measured as the proportion of cues detected and responded to in the manner requested when the intention was formed. Cues can either be specific or general, such as responding to particular words and constructs or to more general categories of items such as fruits or U.S. presidents. The responses could be as simple as marking a response sheet in a particular way, pressing a special key on a keyboard, or rapping on the table when an item is detected.

#### 2.45.3.2 Time-Based Prospective Memory

Another form of prospective memory has been labeled time-based intentions because the intended actions relate to time in some way. The intention could be a relative measure, such as returning a phone call in 30 min, or it could be related to clock time, as in attending a meeting at 1.30 p.m. (note that if the target time were associated with an event or activity and one of these features triggered the intention rather than the monitoring of time, it would not be classified as a time-based task). Not much is known about the mechanisms underlying time-based prospective memory. Most of the work that has been done appeals to a test-wait-test-exit model (see Kvavilashvili and Fisher, 2007). Here the rememberer executes a time check, which is presumably on the first several occasions too early and thus necessitates a cyclical waiting period before another time check is made. As Kvavilashvili and Fisher have so eloquently stated, the problem with this model is that it does not specify what causes a person to engage in a time check in the first place. They conducted a diary study with a long-term time-based intention and found that many remindings were related to chance encounters with objects and language that were direct reminders of the time-based intention. They also found that many such retrievals of the time-based intention came to mind unbidden. We do know that the most successful individuals at time-based prospective memory tasks check the clock frequently in the period just prior to a required response (Einstein et al., 1995). However, that still does not specify what psychological process is responsible for the clock check in the first place, and this is especially true when a participant records in a diary that there was not an external or internal trigger of the time-based intention. Like event-based prospective memory, how many responses are successful is the usual dependent variable, although some metric of being early versus late is also a common variation. Of course, when measured, the distribution of clock checking can also be very informative as well.

#### 2.45.3.3 Activity-Based Prospective Memory

Finally, the third common form of prospective memory measures what is called activity-based prospective memory (e.g., Schaeffer et al., 1998). With this type of intention, people intend on doing one activity after finishing another one. For example, intending on walking the dog after the evening news would represent an activity-based intention. Although this might seem to be a habitual intention, whether something is novel or habitual depends on the frequency with which it is carried out, and this applies equally well to event-based and time-based tasks. There have not been many experimentally based studies on activity-based prospective memory, probably because there is some theoretical ambiguity about whether this is just a special form of an event-based task, with the conclusion of one task serving as the event that signals responding. However, this ambiguity highlights a very important point concerning prospective memory, namely, the rememberer can form an intention in any of these three different ways, and each will have varying success depending on tasks and conditions that prevail on that occasion. Take the simple intention of purchasing a birthday card. One could write oneself a note and hope that seeing the note was sufficient to accomplish the task (an event-based task). One could formulate the intention to run to the store right after lunch in order to carry out the purchase (an activity-based intention). Or, one could plan a specific deviation of one's day and commit to leaving the office at 5.00 p.m. to carry out the task (a time-based task). All three formulations are prospective memory tasks, but they will vary in the success rate depending on the individual and the conditions surrounding the performance interval (e.g., seeing the note but being late for work or for a class). The important point is that a desire to accomplish some goal can be linked to various future contexts in a variety of ways depending on whether the rememberer gives some serious consideration to what formulation will be best (for a more detailed treatment of prospective memory and contextual associations see Marsh et al., in press).

### 2.45.4 Retrieval of Prospective Memories: Retrieval Without an Explicit Request to Remember

A central problem in prospective memory is in understanding how we initiate an intended action at the appropriate moment. This is an interesting question because models of retrospective memory retrieval (e.g., recall and recognition) start with the assumption that people have been put in a retrieval mode and have been explicitly directed to search their memory for previously encoded information. As discussed earlier, prospective memory is different in the sense that we form an intention to perform an action at some later point and then get busily involved in other activities. How, then, do we remember to perform the action in response to that event? Because the majority of the research has investigated retrieval on event-based tasks, this is our focus in this section. Following, we consider two opposing theories that address this question and then present a compromise view. (For those interested in research and theorizing on retrieval of time-based prospective memories, we recommend the following sources: Harris and Wilkins, 1982; Harris, 1984; Ceci and Bronfenbrenner, 1985; Block and Zakay, 2006; Kvavilashvili and Fisher, 2007.).

### 2.45.4.1 Attentional Monitoring Theory

The attentional monitoring view assumes that some of our attentional and/or working memory resources need to be devoted to monitoring the environment for the target event in order for retrieval to occur. According to this view, successful prospective memory requires that an attentional system like Shallice and Burgess's (1991) supervisory attentional system monitors the environment in light of our prospective memory demands. When a target event is detected, this system interrupts the ongoing activity, evaluates whether the conditions for performing the action are appropriate, and if so initiates the appropriate actions.

The most thoroughly developed statement of this view is Smith and Bayen's (Smith, 2003; Smith and Bayen, 2004, 2006) preparatory attentional and memory (PAM) theory. According to this theory, when we form an intention, we initiate a capacity-consuming preparatory attentional process that monitors environmental events by initiating recognition checks to determine whether the events are instances of the prospective memory target. For example, consider the task presented in **Table 1**, in which the prospective memory task is to press the slash key when the target word 'rake' occurs while performing the ongoing pleasantness rating task. According to the PAM theory, preparatory processes involve initiating a recognition check for each item to determine whether it is an instance of the target event and could also include rehearsing the target event. According to this theory, forgetting occurs when people fail to maintain their attention on the intention and therefore fail to initiate recognition checks, or when there is a recognition failure (see Smith and Bayan 2004, 2006, for a multinomial model that measures these two parameters). Smith takes a strong position on the necessity of monitoring for successful prospective memory, arguing that "capacity must be devoted to the prospective memory task in the form of monitoring before a target event occurs if the target is to be recognized as a signal or an opportunity to perform the prospective memory action" (Smith, 2003, p. 359).

Because this view assumes that people are using attentional resources to monitor the environment for target events when they have a prospective memory intention, this view clearly predicts that adding a prospective memory task to an ongoing task should produce task interference (i.e., slowing on the ongoing task). Continuing with the example, the idea is that the pleasantness ratings for nontarget items will be slower because subjects are additionally monitoring these items for the prospective memory target event while they are performing the pleasantness ratings. Smith (2003, Experiment 1) provided strong support for this view when she found that participants were approximately 300 ms slower in performing a lexical decision task when they were also performing a prospective memory task compared with when they were performing the lexical decision task alone. Task interference to the ongoing task has been found repeatedly and with other types of ongoing tasks (Smith and Bayen, 2004) and in other labs (Marsh et al., 2003; Einstein et al., 2005). Moreover, Smith (2003) found that individuals who showed more task interference (i.e., more slowing on the ongoing task as a result of performing the prospective memory task) had higher prospective memory, thereby indicating that monitoring is important for prospective memory retrieval.

The monitoring view is also supported by research showing that dividing attention during retrieval lowers prospective memory (Einstein et al., 1997; Park et al., 1997; Marsh and Hicks, 1998). Marsh and Hicks have shown that divided attention tasks that required central executive resources, but not ones that increased the demands of articulatory suppression or visuospatial involvement, reduced prospective memory performance. A straightforward interpretation of these results is that dividing attention compromises monitoring processes that are needed to identify prospective memory targets.

### 2.45.4.2 Spontaneous Retrieval Theory

A different way to think about prospective memory retrieval is to assume that the occurrence of the target event can trigger remembering even when no resources are devoted to the intention at the time that the target event occurs (Einstein and McDaniel, 1996; McDaniel and Einstein, 2000; McDaniel et al., 2004; Einstein et al., 2005). Much like walking by a friend can reflexively trigger the recollection of an amusing past episode with the friend (when there was no prior intention to remember that episode prior to encountering the friend), according to the spontaneous view, it is the occurrence of the cue that triggers processes that lead to retrieval of the intended action. Within this view, then, monitoring or preparatory attentional processes are not necessary for successful retrieval.

In this section, we briefly review two theoretical mechanisms by which spontaneous retrieval can be accomplished. One theory, called the reflexive-associative theory (Einstein and McDaniel, 1996; McDaniel and Einstein, 2000; McDaniel et al., 2004), assumes that relatively automatic processes can underlie prospective memory retrieval. The idea is that during planning, people form an association between the target cue and the intended action (e.g., an association between the target word 'rake' and the action to press the slash key). Later, when the target event is processed in the context of the ongoing task, an automatic associative system (like the one proposed by Moscovitch [1994] and presumed to be mediated by the hippocampal system) retrieves the intended action and delivers it to consciousness. According to Moscovitch, the hippocampal system is an associative module that mediates associative encoding and associative retrieval. If we have formed a good association between the target cue and the intended action, and if the cue is fully processed at retrieval, then this associative module should rapidly, obligatorily, and with few cognitive resources deliver the intended action (press the slash key) to consciousness.

There are several results that are consistent with this theory. One comes from introspective reports of participants who often remark that the thought to perform the intended action appeared to pop into their mind while performing the ongoing task (Einstein and McDaniel, 1990). Also, Reese and Cherry (2002) found very little evidence that participants were monitoring while performing an ongoing task. They probed participants at various points during the ongoing task and asked them to indicate what they were thinking about. Both younger and older adults rarely indicated thinking about the prospective memory task (less than 5% of the time, compared with reporting thoughts of the ongoing task about 69% of the time). Even so, prospective memory performance was at a reasonable level (about 60%). Also consistent with the spontaneous retrieval theory is the finding that subjects who demonstrate no costs or task interference when performing an ongoing task (and are therefore unlikely to be monitoring) can still exhibit very high levels (93%) of prospective memory (Einstein et al., 2005, Experiment 4). We should also note that the previously described findings of negative effects of dividing attention on prospective memory do not unambiguously argue against spontaneous retrieval. At this point in our research, it is not clear exactly how dividing attention affects performance. For example, dividing attention may interfere with full processing of the target event, which may be essential for good spontaneous or associative retrieval (Moscovitch, 1994). Or, it may not interfere with retrieval of the intention but, instead, may increase working memory demands to such a degree that participants have difficulty selecting the retrieved intention and scheduling the intended action while it is still activated in working memory (Einstein et al., 1997).

The discrepancy plus attribution theory also explains how retrieval can occur spontaneously and in the absence of monitoring. It assumes that the processing of the target event leads to a feeling that there is something significant about the event, and this in turn leads to a search of memory for an explanation of its significance. Depending on how well the intention was encoded, this search at retrieval can lead to the realization that the event is a cue for an intended action. According to Whittlesea and Williams (2001a,b), people chronically evaluate the quality and coherence of their processing, and they are sometimes sensitive to the discrepancy between the actual quality of processing and the expected quality of processing in that context. This sense of discrepancy is alerting and begs for an explanation, which in the context of a recognition task could lead to the interpretation that the item has been seen before. McDaniel et al. (2004) proposed that these processes can also explain prospective memory retrieval. Specifically, the idea is that the target event, on the basis of its initial processing during the encoding of the intention, will, when it appears again in the context of the ongoing task, be processed more fluently (than other items in the ongoing task), and this discrepancy is likely to elicit a sense of significance. In turn, this noticing can lead to a search of memory for the source of the significance, and this can lead to the realization that the event is a cue for an intended action.

There has been recent support for this theory from research manipulating the prior exposure of the target item relative to the ongoing task items. McDaniel et al (2004) created a high-discrepancy condition by presenting the target words during the initial instruction and not preexposing the nontarget items. That is, none of the ongoing task items appeared in a preceding list-learning task, but the prospective memory target item appeared during the instructions for the prospective memory task items. In this condition, the target item should have been processed more fluently relative to the ongoing task items and thus should have produced discrepancy and a sense of significance. In the low-discrepancy condition, the ongoing task items were preexposed in a preceding list learning task. Thus, there should have been less discrepancy in the fluency of processing the target items relative to ongoing-task items. Consistent with the discrepancy attribution theory, prospective memory performance was better in the high-discrepancy condition than in the low-discrepancy condition.

Breneiser and McDaniel (2006) have recently provided additional support for this theory by showing that it is not simply greater familiarity for the target item but, rather, the discrepancy between the actual quality of processing and the expected quality of processing that is critical for determining a sense of significance. They found that preexposing ongoing task items four times each in a preceding list-learning task relative to one preexposure for the target items (high-discrepancy condition) led to better prospective memory performance than one preexposure of both the target and ongoing task items (low-discrepancy condition). Other evidence consistent with the general idea that discrepancy can stimulate a search for significance comes from research showing that manipulations that increase the noticing of the target event, such as making the target event distinctive (e.g., a target word presented in upper case letters with the ongoing task items in lower case letters), produced very high prospective memory performance (McDaniel and Einstein, 1993; Brandemonte and Passolunghi, 1994).

### 2.45.4.3 Multiprocess Theory

So, which processes do we rely on for prospective remembering? According to the multiprocess view (McDaniel and Einstein, 2000; see also Einstein and McDaniel, 2005; Einstein et al., 2005; McDaniel and Einstein, 2007: Chapter 4), there are many reasons to believe that the human cognitive system uses both monitoring and spontaneous retrieval processes for prospective remembering. First, given the prevalence and importance of prospective memory demands in the real world, it would be adaptive to have a system that relies on multiple processes for prospective memory retrieval and thus increases the chances that we will remember under a variety of conditions. Second, given that the delays between forming an intention and the opportunity to execute the intention are often substantial (on the order of several hours or more), it would seem maladaptive to have a system that relied exclusively on capacity consuming monitoring processes for successful retrieval. In Smith's (2003) research, for example, monitoring for target events slowed down lexical decision times by about 45% (Experiment 1). If we relied entirely on monitoring processes for successful prospective remembering, then the efficiency with which we performed the intervening ongoing activities in our lives would be severely compromised. Third, the view that participants sometimes (perhaps most often) rely on spontaneous retrieval processes fits with Bargh and Chartrand's (1999) theory that we have a limited capacity for conscious control over behavior and therefore much prefer to rely on automatic or unconscious processes. Consistent with this idea, several studies have shown that exerting conscious control over behavior in one phase of an experiment leads subjects to expend less conscious effort in a later phase (e.g., Baumeister et al., 1998). From this perspective, the cognitive system is limited in the extent to which it is able to maintain controlled monitoring of the environment for target events.

Fourth, the idea that we sometimes rely on spontaneous retrieval processes and sometimes augment these processes with capacity-consuming monitoring processes has the potential to explain some apparently inconsistent results. For example, although dividing attention often interferes with prospective memory, there are conditions under which dividing attention has no effect on performance (McDaniel et al., 2004). An explanation of this pattern of results is that dividing attention will interfere with prospective memory primarily in those conditions in which monitoring is useful for prospective memory retrieval but will have minimal effects under those conditions in which spontaneous retrieval processes are effective in producing retrieval.

There are three assumptions to the multiprocess view. One is that prospective remembering can be supported by several different kinds of processes ranging from strategic monitoring of the environment to spontaneous retrieval processes. A second assumption is that the process that people rely on in a particular situation and the effectiveness of that process for producing retrieval depend on a host of factors, including the nature of the prospective memory demand, the demands and characteristics of the ongoing task, and the characteristics of the individual. For example, if people can anticipate that they will later encounter a salient retrieval cue for prospective memory, they are more likely to rely on spontaneous retrieval processes. If, on the other hand, it would be catastrophic to forget the intended action and the delays are fairly brief, people may initiate and maintain an active monitoring strategy over the delay interval. A third assumption, and in line with the theory of Bargh and Chartrand (1999) noted above, the multiprocess theory assumes that people have a bias to rely on spontaneous retrieval processes.

As just noted, according to the multiprocess theory, certain conditions make it more likely that the presence of the target event spontaneously triggers retrieval of the intention (McDaniel and Einstein, 2000; see McDaniel and Einstein, 2007: Chapter 4, for further discussion of relevant variables). Assuming good encoding of the intention, an important variable, for example, is the extent to which the ongoing task encourages focal processing of the target event. This idea, which is an extension of the retrospective memory theory of transfer-appropriate processing (see more about this later, and see Morris et al., 1977), is that spontaneous retrieval is likely to occur to the extent that the ongoing task directs attention to the target event and encourages processing of those features that were processed at encoding or planning (see **Table 2** for examples of conditions McDaniel and Einstein believe do and do not encourage focal processing). On the other hand, with nonfocal cues, spontaneous retrieval is less likely, and successful retrieval is more dependent on monitoring for the target event.

The multiprocess theory assumes that subjects are generally sensitive to the conditions that lead to spontaneous retrieval (e.g., focal cues) and those that demand active monitoring for the target event (e.g., nonfocal cues). This idea is similar to that of Marsh et al. (2003; see also Marsh et al., 2006), who believe that subjects develop an allocation policy that is based on their perceived difficulty of performing the ongoing task and the prospective memory activities. For example, if subjects believe that the prospective memory task will be difficult, they will allocate attentional resources to monitoring for the

**Table 2** Representative examples of task conditions, some of which have been used in published research, that we assume are high and low in focal processing

| *Processing* | *Ongoing task* | *Prospective memory task* |
|---|---|---|
| Nonfocal | Words were presented in the center of a computer monitor and participants had to learn them for recall tests that occurred at unpredictable times. | Respond when you see a particular background pattern (background pattern changes every 3 s). |
| Focal | Participants had to keep track of the number of occurrences of each background screen pattern. | Respond when you see a particular background pattern (background pattern is changed every 3 s). |
| Nonfocal | Lexical decision task | Respond to items from the animal category. |
| Focal | Lexical decision task | Respond to the word ‘cat.’ |
| Nonfocal | Pairs of words were presented, and participants decided whether the word on the left was a member of the category on the right. | Respond to the syllable ‘tor.’ |
| Focal | Pairs of words were presented, and participants decided whether the word on the left was a member of the category on the right. | Respond to the word ‘tortoise.’ |
| Nonfocal | Pictures of famous faces were presented, and the task was to name the face. | Respond when you see a face with eyeglasses. |
| Focal | Pictures of famous faces were presented, and the task was to name the face. | Respond when you see a face with the first name of John. |

From Einstein GO and McDaniel MA (2005) Prospective memory: Multiple retrieval processes. *Curr. Dir. Psychol. Sci.* 14: 286–290.

target event. Marsh et al. believe that this allocation policy is dynamic and varies in response to subjects' changing perceptions of the difficulty of prospective memory and ongoing tasks change.

## 2.45.5 Storage of Prospective Memories: Do They Enjoy a Privileged Status in Memory?

Because prospective memories are formed with the goal of later retrieving them in the appropriate context, some researchers have suggested that they may have special storage properties. Indeed, Goschke and Kuhl's (1993) seminal work suggests that intentions may hold privileged status in memory. In their work, participants were asked to learn pairs of scripted actions for, say, clearing a messy desk or setting a table (e.g., actions might be: distribute the cutlery, polish the glass, light the candle, etc.). After learning, participants were told that one script in the pair would have to be performed later. In an immediate recognition test, latencies were faster to words coming from the to-be-performed script as opposed to the neutral script about which there was no prospective intention. Marsh et al. (1998a) replicated this decreased latency effect using a lexical decision task but also discovered that if the assessment of activation came after performing the script, then latencies were slower to the already-performed script as compared with the neutral script. Applying the standard interpretation that faster latencies are associated with information being more accessible in memory, Goschke and Kuhl concluded that prospective memories enjoy a privileged status in memory, whereas Marsh et al. concluded additionally that a prospective memory, once completed, goes into a state of being temporarily inhibited, which could be ecologically adaptive in planning what activities one has to do next.

There are converging reports to suggest that prospective memories reside in a privileged state. For example, Maylor et al. (2000) asked younger and older adults to list their plans for the coming week and also to list what they completed in the previous week. The conditions under which they did so were speeded, and participants were asked to write two or three words to describe each future intention or each completed intention. Consistent with the intention superiority effect (ISE), younger adults listed more future plans than they did completed activities, ostensibly because the future plans were more available in memory. In contrast, the older adults did not. Lebiere and Lee (2002) modeled Marsh et al.'s (1998) data using the ACT-R assumptions (Anderson and Lebiere, 1998) that prospective memories represent a goal node in that model. According to ACT-R, goal nodes receive constant sources of activation, and this facet of the model would account for their higher accessibility in memory. In measuring cue interference, Marsh et al. (2002b) found that prospective memory cues that were missed (i.e., that were not detected and that had received no prospective memory response) in a lexical decision task were responded to more quickly than control-matched items. Because they used a categorical intention to respond to animals, Marsh et al. assumed that they had found a more specific version of the ISE. That is, because intention-related material has privileged accessibility, it is processed more quickly even when the cue does not elicit a prospective memory response (but see West et al., 2005).

Marsh et al. (2008) have recently reported a related, very provocative finding. In this study, participants were asked to pay attention to a visual stream of words and actively ignore the information presented in an auditory channel. The participants were also given the prospective memory task of responding to a categorical intention (e.g., vegetables) when an exemplar appeared in the visual channel of information. Participants were then tested on their memory for only information presented in the to-be-ignored auditory channel. Recognition of intention-related material in the to-be-ignored channel was significantly better than control-matched material in the same channel. Marsh et al. interpreted these results as consistent with the ISE, in which intention-related material gains more obligatory access to consciousness than comparable material about which there is no intentionality.

As an alternative to the ACT-R account, if one assumes a network model of memory, then whenever plans and intentions are considered or otherwise brought into consciousness, some small amount of activation might accrue to other plans and intentions, and this process could keep them in a higher baseline resting state. Combined with a view that prospective memories are revisited from time to time, whereas retrospective memories probably receive fewer such rehearsals, then perhaps some confluence of these different explanations is what actually confers a special status on prospective memories. Of course, this general perspective is not without its opponents. In their original report, Marsh et al. (1998; see also

Marsh et al., 1999) were somewhat skeptical that a critic would necessarily adopt the notion that prospective memories were stored in a more accessible fashion. They argued that an alternative conception of the ISE is that prospective memories reside as declarative representations with the same level of baseline activation in their resting state as do retrospective memories. As such, prospective memories may be able to be revived faster because they are more elaborately encoded or because they are related to one's self schema. Also, Freeman and Ellis (2003) report boundary conditions on the ISE. In their report, they used subject-performed tasks (e.g., clap your hands), and they found an ISE only with verbal encoding and not if people learned the tasks motorically. Consequently, the ISE may be a verbal learning phenomenon. If so, this finding may not really constrain the generality of the effect because most of our everyday intentions are self-generated from thoughts.

There are no published reports contravening the ISE other than Maylor et al.'s (2000) failure to find the effect in older adults and Freeman and Ellis's (2003) failure to find it with motoric encoding. Unfortunately, this does not mean that the ISE is not a major contributor to the file drawer problem. After the Marsh et al. (1998) article appeared, Richard Marsh was contacted by many people for stimulus materials expressing an interest in testing older adult populations in order to assess whether older adults fail to inhibit after completing a prospective memory task. Because none of these reports have appeared in the last decade, one cannot help but wonder just how robust the ISE truly is. Of the many effects found in prospective memory, the ISE stands alone because it is a tantalizing proposition that the human memory system would have evolved to single out our ancestors' intentions as privileged material. Of course, from an evolutionary perspective, it would be advantageous if our ancestors who were proactive about finding food, water, shelter, and a mate survived and thrived more readily as opposed to being reactive toward these basic needs. The ISE is one of those phenomena in the realm of prospective memory that needs to be scrutinized more carefully than it has been in the scientific record to date. Only a handful of reports have been published on the effect, but any theoretical influence the ISE has on clock checking or the probability of an event-based cue being recognized needs to be based on a deeper understanding of the basic phenomenon and why it occurs.

## 2.45.6 Encoding of Prospective Memories

The work on encoding has reflected two general orientations: (1) the influence on prospective memory performance of instructions or experimental conditions that guide encoding of the intention to perform an action in the future (including encoding of the target event that signals the appropriateness of performing the intention) and (2) the nature of planning processes that people display in the absence of instructions directing specific encodings. Most of the research has centered on the first topic, and accordingly our review concentrates on that research.

### 2.45.6.1 Associative Encoding

A primary finding is that instructions or conditions that foster associative encoding of the target cue and the intended action tend to improve prospective memory performance. This finding resonates well with the reflexive associative theory presented earlier. Several aspects of this finding merit amplification. First, as is elaborated later, associative-encoding manipulations do not always produce improvements in prospective memory, and this may be because of the nature of laboratory tasks. In laboratory prospective memory tasks, where the participants are instructed to perform an intended action in the presence of a particular cue event, it is especially likely that people are spontaneously encoding a target cue–intended action association. Consequently, instructions specifically designed to augment such associative encoding could be redundant with the encoding already engaged by participants.

A second key pattern is that prospective memory effects of at least one type of associative-encoding manipulation may be accompanied by signatures of spontaneous retrieval. This pattern is consistent with the reflexive-associative theory described earlier that assumes that retrieval of an encoded target cue–intention association can be mediated by an automatic associative memory system.

One general technique to stimulate associative encoding that people can be instructed to use is an implementation intention (Gollwitzer, 1999). An implementation intention specifies situational cues for initiating an intended action and a technique to link these specific cues to the intention by using a condition-action statement such as: If situation *x* arises, I will perform *y*. However, in the experimental work on prospective memory, laboratory instantiations of an implementation intention have varied. Cohen and Gollwitzer's (2007) implementation intention required subjects to write down three times the implementation intention (e.g., "If I see the word *window* at any point in the task [lexical decision], I will say *wrapper* as fast as possible!"). The implementation intention produced a significant advantage in prospective memory over a standard prospective memory instruction that simply told participants to say a response word upon seeing the cue word (but without repetitive writing of the instruction), even though the standard instruction group displayed relatively high prospective memory performance.

In other experiments, the implementation intention involved both saying aloud the condition–action statement and a period of encoding (typically 30 s) during which subjects imagined themselves performing the intended action upon seeing the target cue (Chasteen et al., 2001). Prospective memory performance improved under these conditions relative to a control not given implementation intention instructions for both younger adults (Howard et al., 2006) and older adults (Chasteen et al., 2001). Furthermore, it appears that the imagery encoding alone is not sufficient to produce the benefits (Einstein et al., 2003, Experiment 3; Howard et al., 2006, Experiment 2), even though imagery encoding would presumably be fostering associative linkages between the target event and the behavior (McDaniel and Pressley, 1987). Thus, based on current evidence, it seems that the full implementation intention procedure (imagery plus the if … then statement) is most likely to create positive effects of this kind of associative-encoding instruction.

It is important to note, however, that the full implementation intention procedure does not always yield improvements in prospective memory (Kardiasmenos et al., 2004; Bennett et al., 2005; see also Chasteen et al., 2001; Howard et al., 2006, for other instances of null effects with implementation intentions). These findings dovetail with the first point made above. Participants under standard prospective memory instructions may at least sometimes spontaneously form good associative encodings of the target cue–intention action, thereby rendering experimenter-instructed associative encoding procedures unnecessary.

Another possibility is that even when implementation intentions do not affect levels of prospective memory, the processes underlying prospective memory retrieval may be altered. Under standard prospective memory instructions, attention-demanding retrieval processes (e.g., monitoring) might be recruited (processes that in some cases support relatively high levels of prospective memory; McDaniel et al., 2006; Cohen and Gollwitzer, 2007), whereas with an implementation intention, encoding relatively automatic retrieval processes may prevail (see section 2.45.4 for details of these processes). The limited evidence is consistent with this possibility. For instance, in Cohen and Gollwitzer (2007), response times to the ongoing activity (lexical decision) did not differ between the implementation intention condition and a control for which there was no prospective memory task (implicating relatively spontaneous retrieval processes), yet in the standard prospective memory condition, the response times were significantly longer relative to the no-prospective memory control (this cost implicating a demanding process for prospective memory). Further, Howard et al. (2006, Experiment 2) substantially increased the demands of the ongoing activity (by requiring random number generation as a secondary task). Prospective memory performance significantly declined relative to a condition without the demanding ongoing activity (random number generation was not required) with standard prospective memory instructions but not with implementation intention instructions.

The benefits of focusing encoding on the association between the target cue and the intended action are underscored by another type of finding. In one paradigm, after encoding the prospective memory intention, participants were interrupted several times during the ongoing task and re-presented with aspects of the prospective memory instructions (Guynn et al., 1998, Experiment 3). Some participants were presented with only the target cues, others were presented with the intention, and still others were presented with the target cues and the associated intended action. In all cases, participants were instructed to think only about the information presented. Thus, these conditions reflect additional encoding of target cues, the intention, or both. The differences in prospective memory performance as a function of the type of additional encoding were pronounced. Additional encoding of target cues alone and intention alone produced relatively low performance (36% and 56% prospective memory responding, respectively), whereas additional encoding of the target cue–intention pairs promoted high prospective remembering (82%).

### 2.45.6.2 Target Cue Encoding

An interesting aspect of the above results is that repeated encoding of target cues produced no increases in prospective remembering relative to a single-encoding control condition. Ample evidence indicates, however, that the quality of the target-cue encoding plays a role in successful prospective remembering. Paralleling the retrospective memory literature, semantic encoding of the target cue tends to improve prospective memory performance relative to nonsemantic encoding (McDaniel et al., 1998, Experiment 3), generating the target cue at encoding improves prospective remembering relative to reading the target cue (Matthews, 1992; Robinson-Riegler, 1994, Experiment 1), and presenting the referent of the target cue as a picture at encoding produces better prospective memory performance than presenting the cue as a word (even when the presentation of the cue during retrieval is in a different modality than at encoding; McDaniel et al., 1998, Experiment 2). Similarly, dividing attention during encoding of the target-cue significantly attenuates prospective remembering (Einstein et al., 1997).

Further, elaboration of the target-cue prior to its specification as a prospective memory target event appears to enhance prospective remembering. In one study, prior to the prospective memory instructions, some participants repeatedly generated the target cue (from word fragments or anagrams). These participants evidenced high levels of prospective memory under both standard and demanding ongoing task demands. In contrast, participants who generated words that were not subsequently used as targets displayed a significant reduction in prospective memory when ongoing task demands became more challenging (Guynn and McDaniel, in press; see Mantyla, 1994, for a similar finding).

It is worth noting that the positive effects of elaborative encoding of the target cue are entirely compatible with the theories of prospective memory retrieval reviewed in the preceding section. Such encoding would be expected to lead to better recognition of the cue during the retrieval period (assuming the PAM theory) or to create more discrepancy between subsequent processing of the target cue and nontarget events (assuming the discrepancy-attribution processes), thereby facilitating noticing of the target cue in the retrieval context. Even the reflexive-associative approach assumes that interaction of the cue with a memory trace (e.g., the intended action) is facilitated by initial encodings that are more semantic or distinctive (Moscovitch, 1994).

## 2.45.7 Similarities and Differences Between Prospective and Retrospective Memory

Given the formal distinction between prospective and retrospective memory, it may be tempting to focus on their differences and perhaps even to appeal to different memory systems; however, this approach would overlook many similarities as well as undercut our exploration of how our rich conceptualization of retrospective memory can help us understand prospective memory (see Marsh et al., 2006, for a more detailed treatment of the similarities and differences between retrospective and prospective memory). As a fundamental starting point, consider that prospective memories share three basic stage-like histories with retrospective memories, namely, encoding, retrieval, and any changes that occur over a retention interval (as reflected in the content of the previous sections; cf. Ellis, 1996). Intentions occur as a function of direct requests from others, or they are self-initiated. No work to date has experimentally examined the fate of these two basic types of intentions. However, even a cursory analysis or Gedanken experiment would suggest that the former type should go unfulfilled more frequently than the latter (with notable exceptions arising such as not breaking social contracts). The reason for this is twofold. First, self-generated information may undergo more rehearsals because it is self-referential in nature. Second, prospective memories that are self-referential may be more elaborately encoded and better linked to present and future contexts. More generally, for both of the same reasons that self-defined intentions may be completed more often than requests from others, prospective memories may be more durable than retrospective memories as a consequence of the manner in which they are encoded and/or rehearsed (see West and Krompinger, 2005, for an empirical approach designed to maximize similarities in order to identify fundamental differences).

To elaborate, when an intention is formed, a host of self-referential information is stored, such as why we want to complete the task, the costs and benefits of doing (or not doing) so, the current context, and the future context we might be in at the time of completion. Because material that is related to one's self is better remembered (e.g., Klein and Kihlstrom, 1986), prospective memories may be more durable than otherwise equivalent retrospective memories. More elaborated intentions that are stored more durably in memory also should have a higher probability of coming to mind during the retention interval. Just like a retrospective memory, the more frequently a memory is rehearsed, the better it will be recalled on a subsequent occasion (called retrieval sensitivity by Mäntylä, 1994). So, based on the properties of encoding, one cannot make a blanket statement that all prospective memories will be remembered more faithfully than retrospective memories, only that on average, the amount of effort expended in creating a prospective memory could be greater than in creating a simple, everyday retrospective memory. In addition, the contextual details surrounding retrospective memories are usually lost quite quickly (e.g., Bornstein and LeCompte, 1995), whereas they often form the core of a prospective memory. For example, we often plan to fulfill a prospective memory in a particular context, and therefore, a prospective memory will have linked with it at least two contexts (the environment during formation and the one in which we expect to do it). These can serve as important retrieval cues to fulfilling intentions, and when contexts mismatch our expectations, then the consequences can be very grave indeed for intention completion (Cook et al., 2005).

As we said earlier, retrieving intentions is usually a self-initiated act, whereas many times retrieving retrospective memories is not. Of course, exceptions to this rule exist, such as when a third party queries you about your intentions (e.g., "Got plans for this weekend?"). Nevertheless, when we rely on retrieval cues, many of the principles of prospective memory appear to mimic what has been found with retrospective memory. For example, if one has the intention to respond to a word such as 'bat' (as in baseball), then receiving the cue as bat (as in mammal) leads to much worse prospective memory (McDaniel et al., 1998). A form of transfer-appropriate processing is also found in what is known as task-appropriate processing (Marsh et al., 2000; West and Craik, 2001; Maylor et al., 2002). If the features of the ongoing task focus one on the correct aspects of the prospective memory cue, intention retrieval is more successful. As such, a semantic intention to respond to words denoting animals is more successful if the ongoing task encourages semantic, as opposed to orthographic, processing of the items. Also, resource sharing during retrieval appears to have similar effects on prospective and retrospective memories. Dividing attention during either encoding or retrieval generally reduces retrospective memory (Baddeley et al., 1984; Craik et al., 1996) and prospective memory (e.g., Einstein et al., 1997, 1998; McDaniel et al., 2004). One possible difference is that some forms of event-based prospective memory require difficult, centrally mediated divided attention tasks to observe lower rates of responding to prospective memory tasks (Marsh and Hicks, 1998).

Finally, prospective and retrospective memories both share the property that they will change over the course of a retention interval. Obviously, an unrehearsed memory will grow weaker over time and eventually be forgotten. However, most people review their intentions periodically as a part of their daily mental life. Alternatively, cues in the environment can remind us of intentions, such as the sight of one's vehicle serving as a reminder to have the oil changed. These periodic reminders of intentions only serve to strengthen their representation, as we argued earlier. Most retrospective memories do not enjoy such periodic revisitation and more likely fall into desuetude, thereby requiring increasingly stronger retrieval cues over time to recover that information.

## 2.45.8 Development and Prospective Memory

Although there has been much interest in examining prospective memory from developmental perspectives, most of it has been conducted with older adults. This focus on older adults is probably a result of the obvious practical importance of understanding how aging affects prospective memory (e.g., to help inform health care issues related to prospective memory such as medication adherence), but also in response to compelling theoretical issues. We briefly review first the literature with children and then the research with older adults. As might be expected, the research generally shows that older children outperform younger children and younger adults outperform older adults on prospective memory tasks. However, it is also clear that the age differences vary greatly across prospective memory tasks and that there are some tasks on which no age differences are found. Thus, an interesting theoretical and applied challenge for prospective memory researchers is to understand those conditions that are and are not especially difficult for younger children and older adults.

Before reviewing this literature, we briefly raise a methodological issue that is important to consider when examining developmental trends in prospective memory. Given that prospective memory tasks are embedded in ongoing tasks and that demanding ongoing tasks have been shown to interfere with prospective memory (Marsh and Hicks, 1998), it is important to control the demands of the ongoing task across age groups. Otherwise, differences in prospective memory could stem from the ongoing task being functionally more demanding for younger children or for older adults (see Einstein et al., 1997; Kvavilashvili and Fisher, 2007, for discussion of this issue).

### 2.45.8.1 Prospective Memory in Children

Even though there is not a plethora of existing research on prospective memory in children, several interesting results have emerged, and these seem to be stimulating increasing interest (e.g., see Kliegel et al., in press; Kvavilashvili et al., in press). Recent studies examining event-based prospective memory in 5- and 7-year old children generally suggest that age differences are larger on tasks that require more controlled or strategic processes. All of these studies used a variation of Kvavilashvili et al.'s (2001) prospective memory task of asking children to name pictures from stacks of pictures for Morris the Mole because he does not see very well (the ongoing task). The prospective memory task was to hide any picture of animals from Morris because he was scared of them. Kvavilashvili et al. varied whether the animal pictures appeared in the middle or the end of the stack. Five- and 7-year old children both remembered about 75% of the time when the target was at the end of the stack, but the older children did much better than the younger children when the target was in the middle. Thus, the older children were better able to inhibit the ongoing activity in order to perform the intended action. When inhibition was not needed, however, the younger children were as capable of remembering as the older children.

To directly study strategic processes, Stokes et al. (2007) manipulated whether the target event was focal or nonfocal. Children in their study were presented with cards (with four pictures on each card) and asked to name the circled picture on each card (the ongoing task). The prospective memory task was to hide the card if there was an animal on it. In the focal condition, animals always appeared as the circled picture, and thus the ongoing task requirement to name the picture forced processing of the target pictures, which in turn could trigger spontaneous retrieval. In the nonfocal condition, the target picture always occurred in a noncircled location, and thus subjects had to remember to monitor the other locations for the target picture. Whereas the prospective memory performance of the older children was nearly perfect regardless of the cuing condition (around 95%), prospective memory was much higher for the younger children in the focal condition (68%) than in the nonfocal condition (20%). Consistent with this pattern, McGann et al. (2005) found high performance and no differences between 5- and 7-year old children with salient target pictures (when the pictures were larger than others) but higher performance for the older children (relative to the younger children) with nonsalient target pictures. All of these studies suggest that some prospective memory conditions are more difficult for younger children than others. Consistent with the general developmental trend showing that younger children have more limited attentional and working memory resources (e.g., Guttentag, 1984) and with the multiprocess theory (McDaniel and Einstein, 2000), younger children seem to have greater difficulty with prospective memory tasks that require active monitoring of the environment and inhibiting the demands of the ongoing task.

Very little research has examined time-based prospective memory in children. An interesting question with this kind of task is whether children can develop and maintain a clock checking strategy in the absence of a cue to trigger remembering. Ceci and Bronfenbrenner (1985) asked 10- and 14-year-old children either to remember to remove cupcakes from the oven or to remove cables from a battery charger exactly 30 min later. The children performed these tasks either at home or in the laboratory. During the 30-min interval, they were engaged in an entertaining video game, and there was a wall clock at their back. This arrangement allowed the researchers to record monitoring of the clock. Interestingly, most children developed a monitoring strategy, but the strategy varied across the laboratory and home contexts. In the lab, the children monitored the time increasingly more often as the target time approached. In the home setting, children tended to adopt what Ceci and Bronfenbrenner described as a more adaptive U-shaped monitoring pattern. That is, they monitored frequently initially (presumably to calibrate the passage of time) and then very little after that except for the last 5 min before the target time (at which point they monitored frequently). This strategy is adaptive in the sense that it frees up resources for the ongoing video task. Although the large majority of both 10- and 14-year-olds remembered on time, late responding was associated with less strategic monitoring. In light of the surprising finding that very young children (2 years old) can show very good prospective memory for tasks that they consider important (e.g., buying candy at the store; Sommerville et al., 1983), it would be interesting to explore the conditions and age at which strategic monitoring develops.

### 2.45.8.2 Prospective Memory in Older Adults

As noted earlier, the majority of the developmental research has focused on aging issues (for recent papers, see Henry et al., 2004; McDaniel and Einstein, 2007: Chapter 7; McDaniel et al., in press; Phillips et al., 2007; Wilson and Park, 2007). This interest was motivated by both practical and theoretical considerations. The applied concerns included that good prospective memory may be especially important for older adults who often have health-related prospective memory needs like remembering to take medication. Craik's (1986) theory, suggesting that prospective memory should be very difficult for older adults, provided the theoretical thrust. Noting that aging affects some retrospective memory tasks more than others, Craik proposed that aging disrupts self-initiated retrieval processes, and therefore that older adults need greater environmental support or external cuing for accomplishing retrieval. This theory helps explain why age differences are often larger with free recall than recognition tasks. Because prospective memory is not accompanied by an external request to remember (i.e., subjects are not put in a retrieval mode), Craik theorized that prospective memory should be especially demanding in terms of self-initiated retrieval and thus particularly difficult for older adults.

The findings remind us that prospective memory is not a unitary concept and that age differences vary as a function of the nature of the task demands and the contexts in which they are performed. One pattern is what Phillips et al. (2007) describe as the age prospective memory paradox, which is the finding that older adults generally perform more poorly on prospective memory tasks in the lab but perform as well as or better than younger adults in naturalistic settings (e.g., remembering to mail postcards or to call the experimenter on designated days). Indeed, Wilson and Park (2007) discuss the high medication adherence of older adults in the face of declining cognitive functioning as another paradox (but see Insel et al., 2006, for evidence of modest levels of medication adherence by older adults). It is not currently clear what produces this reversal of performance across naturalistic and laboratory settings, but Phillips et al. and others (e.g., Kvavilashvili and Fisher, 2007) have suggested several possible explanations including age differences in conscientiousness, views regarding the importance of punctuality, busyness and structure of lifestyle, perceptions of task importance, and use of reminders (see also Wilson and Park, 2007). Another possible explanation is that older adults have greater control over the pacing of their ongoing activities in natural settings (McDaniel et al., in press).

Even in laboratory settings, however, there is a large range of age effects. Many studies show large age-related deficits in prospective memory (e.g., Maylor et al., 1999), whereas some show modest or no age-related declines in prospective memory (e.g., Einstein and McDaniel, 1990; Cherry and LeCompte, 1999). Henry et al.'s (2004) meta-analysis revealed an interesting pattern that prospective memory tasks that required greater degrees of controlled or strategic processing (i.e., ones with less external support, and thus ones that required greater monitoring) were associated with larger age effects than those that could be accomplished by relatively automatic retrieval processes (i.e., those with good external cues that could support spontaneous retrieval processes). From a cursory interpretation of Craik's (1986) theory, this should not happen; all prospective memory tasks should be difficult for older adults. From a deeper analysis, however, if one considers prospective memory to be a general label for a variety of specific tasks that differ in the extent to which they are cued by environmental events, the data may be consistent with the theory. The data also appear consistent with the multiprocess theory, which assumes that, depending on the conditions, people rely on monitoring versus spontaneous retrieval processes to different degrees in different kinds of prospective memory tasks. This is important as it relates to aging because working memory and attentional resources that are assumed to be needed for monitoring are thought to decline with age (Craik, 1986), whereas relatively automatic retrieval processes may remain relatively intact with age (McDaniel et al., in press).

To evaluate this interpretation, Reese (2004) tested younger and older adults and varied whether the prospective memory cues were focal or nonfocal (see **Table 2**; recall that focal cues are thought to stimulate spontaneous retrieval processes, whereas nonfocal cues are thought to require monitoring for successful retrieval). The ongoing task involved remembering short lists of words, and as every new word appeared, the background pattern of the screen changed. In the focal condition, subjects were asked to press a designated key whenever they saw a particular word, whereas in the nonfocal condition subjects were asked to press a designated key whenever a particular background pattern occurred. Consistent with the multiprocess theory prediction, Reese found that the size of the age difference depended on the type of prospective memory cue such that the age difference was smaller with the focal cue (80% for younger vs. 49% for older) than for the nonfocal cue (80% younger vs. 17% older). Sometimes there is no age difference with focal cues (e.g., Einstein and McDaniel, 1990; Cherry and LeCompte, 1999; McDaniel et al., in press) and sometimes, as in this particular experiment, the age difference is reduced but not eliminated (see also Rendell et al., 2007, Experiment 1). Possible explanations for the existence of age differences in some experiments even with a focal cue conclude that younger adults may be more likely to engage in monitoring and thereby increase the chances of retrieval, and that spontaneous retrieval processes may not be entirely spared with age.

In addition to tasks with nonfocal cues, prospective memory tasks that seem to pose special problems for older adults seem to be time-based tasks (Henry et al., 2004), habitual prospective memory tasks (ones in which the intended action is performed repeatedly; Einstein et al., 1998), and those in which the retrieved intention cannot be performed immediately and must be delayed (as when a person remembers to take her/his medication in the bathroom but then needs to maintain the intention until she/he gets to the kitchen; see McDaniel et al., 2003). In closing this section, we note again the striking finding that the magnitude of the age differences varies greatly across studies. We suspect that we will better understand this pattern as we examine the processes that are recruited for different prospective memory tasks and how aging affects these processes.

## 2.45.9 Cognitive Neuroscience of Prospective Memory

Building upon the considerable advances that have been made in our understanding of the cognitive processes underlying the realization of delayed intentions, significant progress has been made in identifying the functional neuroanatomy of prospective memory. The neural basis of prospective memory has been investigated using complimentary methodologies within the neuropsychological, functional neuroimaging, and electrophysiological traditions. Study in these domains has revealed a number of neurological and psychiatric conditions that are associated with impaired prospective memory as well as illuminating the temporal dynamics of the functional neuroanatomy of prospective memory.

### 2.45.9.1 Neuropsychology

Studies using the neuropsychological approach reveal that impairments of prospective memory are observed in a variety of neurological and psychiatric disorders including traumatic brain injury (TBI; Shum et al., 1999), stroke (Cockburn, 1995), epilepsy (Palmer and McDonald, 2000), multiple sclerosis (Bravin et al., 2000), Parkinson's disease (Kliegel et al., 2005), schizophrenia (Shum et al., 2004), and substance abuse (Hefferman et al., 2001). Additionally, other evidence has revealed individual differences in prospective memory associated with genetic expression (Driscoll et al., 2005; Singer et al., 2006). Together, work in the area of neuropsychology converges with several themes that arise from the cognitive psychological literature. A number of studies reveal that damage to or disruption of neural networks involving the prefrontal cortex results in impaired prospective memory (Cockburn, 1995; Burgess et al., 2000). This finding is consistent with evidence revealing that prospective memory covaries with the efficiency of executive functions (typically thought to be dependent on the functional integrity of the prefrontal cortex) and the availability of working memory capacity (Marsh and Hicks, 1998). Also, disruption of the medial temporal lobe memory network results in impaired prospective memory (Palmer and McDonald, 2000). This finding is consistent with theoretical models of prospective memory wherein similar processes are thought to support prospective memory and explicit episodic memory (Einstein and McDaniel, 1996; Guynn et al., 2001).

The effects of mild to severe TBI on prospective memory have been considered in a number of studies. This research reveals negative effects of TBI on measures of time-, event-, and activity-based prospective memory (Shum et al., 1999) that increase with the severity of the injury (McCauley and Levin, 2004). TBI has an adverse effect on multiple phases of prospective memory including intention formation, re-instantiation, and execution, and it may have a lesser effect on intention retention (Kliegel et al., 2004). Consistent with this finding, individuals with TBI can benefit from reminders that are inserted in the middle of task performance (McCauley and Levin, 2004). The magnitude of the effect of TBI on prospective memory is equivalent when focal and nonfocal prospective cues are used (Schmitter-Edgecombe and Wright, 2004), possibly indicating that patients do not benefit from spontaneous processes underlying the recognition of prospective cues (Einstein et al., 2005). There is also some evidence that indices of monitoring for prospective cues may be relatively intact in patients with TBI (Shum et al., 1999; McCauley and Levin, 2004). Studies examining the effects of TBI on prospective memory have revealed a mixed neuropsychological profile, with some, but not other, groups of patients demonstrating impairments of episodic or declarative memory, processing speed, and executive functions (Kliegel et al., 2004; Schmitter-Edgecombe and Wright, 2004; Mathias and Mansfield, 2005), making it difficult to ascertain whether there is a core deficit underlying the effects of TBI on prospective memory.

There is growing evidence that disruption of the frontostriatal dopamine system leads to impaired prospective memory. At least two studies reveal that schizophrenia can produce deficits of time-, event-, and activity-based prospective memory (Shum et al., 2004; Kumar et al., 2005). The effect of schizophrenia may result from a disruption of the representation of intentions as the intention superiority effect is reduced or absent in patients with this disorder (Kondel, 2002), or from a reduction in the efficiency of strategic monitoring processes (Elvevag et al., 2003; Shum et al., 2004). There is also some evidence that prospective memory is disrupted in Parkinson's disease (PD; Katai et al., 2003). Furthermore, the effect of PD on prospective memory may result from a reduction in the efficiency of processes supporting the formation and realization of intentions rather than processes supporting the representation of an intention in memory (Katai et al., 2003; Kliegel et al., 2005). Finally, data from two studies indicate that the recreational abuse of MDMA, or Ecstasy – which is known to be toxic to dopaminergic and serotonergic neurons (Ricaurte et al., 2002) – results in both self-reported (Heffernan et al., 2001) and laboratory-based (Zakzanis et al., 2003) prospective memory deficits.

### 2.45.9.2 Functional Neuroimaging

Data from studies using functional neuroimaging methods generally converge with those from the neuropsychological literature. Specifically, PET and fMRI studies reveal activation of a broadly distributed neural network during the performance of prospective memory tasks that includes the rostral and lateral frontal cortex, structures within the medial temporal lobe, parietal cortex, and the thalamus (Okuda et al., 1998; Burgess et al., 2001; Simons et al., 2006). Functional neuroimaging techniques also reveal neural correlates of processes that may distinguish prospective memory from working memory, vigilance, and divided attention (Reynolds et al., 2003; De Bruycker et al., 2005).

Evidence from one line of research reveals that the recruitment of rostral frontal cortex is important for the realization of delayed intentions (**Figure 3**;

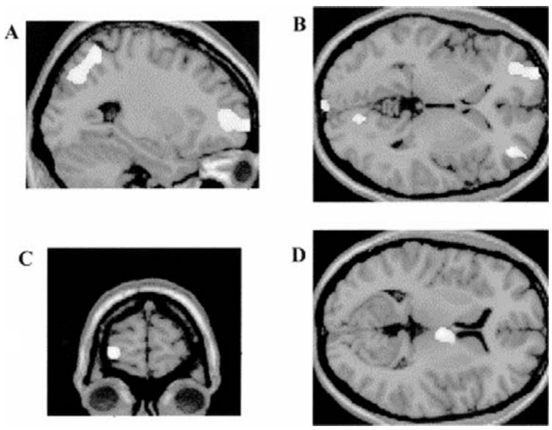


**Figure 3** Functional activation differentiating (execution + expectation) – ongoing alone (a–c) and execution – expectation (d) conditions. Parts (a) and (b) portray activation within lateral rostral PFC, (c) portrays activation in right lateral prefrontal cortex, and (d) portrays thalamic activation. Adapted from Burgess PW, Quayle A, and Frith CD (2001) Brain regions involved in prospective memory as determined by positron emission tomography. *Neuropsychologia* 39: 545–555.

Burgess et al., 2001, 2003). In tasks requiring event-based prospective memory, the lateral rostral frontal cortex is consistently activated, while the medial rostral frontal cortex is often deactivated (Burgess et al., 2003). In contrast, in tasks requiring time-based prospective memory, this pattern may be reversed, revealing activation of medial rostral frontal cortex and deactivation of lateral rostral frontal cortex (Okuda et al., 2001). Variation in the respective roles of the lateral and medial rostral frontal cortex across a variety of tasks has served as the impetus for the development of the Gateway hypothesis, wherein rostral frontal cortex is believed to play a role in switching the focus of one's attention between stimulus-dependent and stimulus-independent aspects of information processing that may be critical for the realization of delayed intentions (Burgess et al., 2005). For instance, as applied to the typical prospective memory paradigm, the rostral frontal cortex may support the ability to switch from a focus on attributes of a stimulus that are relevant to performance of the ongoing activity to a focus on attributes of a stimulus that are internally represented, such as the cue-intention association.

Using PET, Burgess et al. (2001, 2003) sought to determine whether the rostral frontal cortex was involved in the maintenance or realization of delayed intentions. In the baseline condition of these studies, individuals simply performed one of three ongoing activities; in the expectation condition, individuals anticipated the presentation of prospective cues, but cues were never presented; in the execution condition, individuals anticipated prospective cues – and cues were in fact presented. A comparison of neural recruitment in the expectation + execution conditions versus the baseline condition revealed bilateral recruitment in lateral rostral frontal cortex, right parietal cortex, and the precuneus region, while a comparison of neural recruitment in the expectation and execution conditions did not reveal activation in these regions. This finding led to the suggestion that rostral frontal cortex was associated with cognitive processes that support the maintenance of an intention during the delay period (e.g., preparatory processing, Smith, 2003), rather than processes related to the realization of an intention once the prospective cue was detected (Burgess et al., 2001).

fMRI has also been used to examine item-level or event-related neural recruitment associated with processes underlying prospective memory. Evidence from one study reveals what may reflect a neural correlate of item checking described in the strategic monitoring account of prospective memory (Guynn, 2003; Smith, 2003). De Bruycker et al. (2005) compared neural activity for ongoing activity stimuli when the ongoing activity was performed in isolation or when it was performed in the context of a prospective memory task. This comparison revealed increased activation in the medial and lateral extrastriate cortex for ongoing activity stimuli presented during the prospective memory condition relative to the ongoing activity condition. This basic finding was replicated by Reynolds et al. (2003), who observed decreased activation for prospective cues that were presented in a prospective memory condition relative to a simple vigilance condition. The decrease in activation for prospective memory cues from the prospective memory condition to the vigilance condition is consistent with the idea that the addition of a prospective memory component to a task may require the reallocation of processing resources between the prospective and ongoing components of the task (Smith, 2003; Marsh et al., 2006b).

### 2.45.9.3 Electrophysiology

Studies incorporating the event-related potential (ERP) methodology have sought to address three fundamental issues related to the neural basis of event-based prospective memory. First, work in this area has sought to identify the temporal dynamics of the neural correlates of prospective memory. Second, investigations in this area have sought to determine whether the neural correlates of prospective memory can be distinguished from other modulations of the ERPs related to target processing. Third, other investigations have sought to link the neural correlates of prospective memory to cognitive processes described in theories of prospective memory.

Work examining the temporal dynamics of the neural correlates of prospective memory has consistently revealed three modulations of the ERPs that are associated with the realization of delayed intentions (**Figure 4**; N300, parietal old–new effect, and prospective positivity; West et al., 2001; West and Krompinger, 2005). The N300 reflects a phasic negativity over the occipital-parietal region of the scalp that typically emerges between 300 and 400 ms after onset of the prospective cue and is often accompanied by a positivity over the midline frontal region of the scalp (West et al., 2001; West and Ross-Munroe, 2002). The amplitude of the N300 is greater for prospective hits than for prospective misses, leading to the suggestion that it is associated with processes

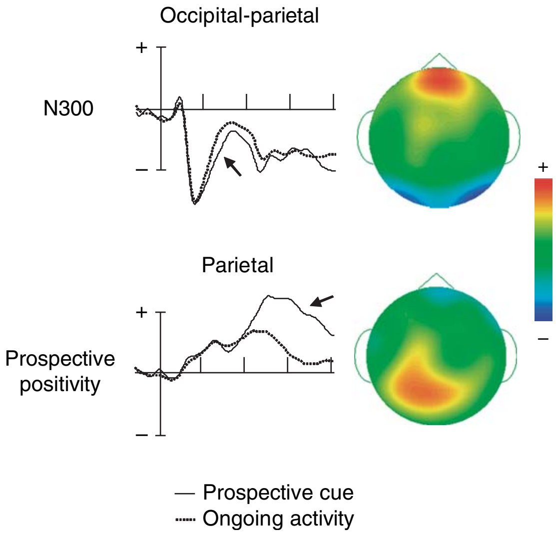


**Figure 4** Grand average ERPs and scalp topography maps as viewed from above, demonstrating the time course and topography of the N300 and prospective positivity. Adapted from West and Wymbs (2004) and West and Covell (2001).

supporting the detection of prospective cues (West and Ross-Monroe, 2002). The N300 is elicited by prospective cues that are defined by letter case, color, and word identity, indicating that it reflects a relatively generic process that is associated with prospective memory (West et al., 2001; West et al., 2003; West and Krompinger, 2005). The parietal old–new effect and prospective positivity reflect enhanced positivity over the parietal region of the scalp between 400 and 1000 ms after stimulus onset (West et al., 2001; West and Krompinger, 2005). The parietal old–new effect reflects a relatively general process that is associated with item recognition in recognition memory (Rugg, 2004) and prospective memory paradigms; the prospective positivity is more specific to prospective memory and may reflect processes that serve to coordinate the prospective and ongoing components of the task once the prospective cue is detected and the intention is retrieved from memory (West and Krompinger, 2005).

An example of research addressing the second issue is portrayed in a study comparing the prospective positivity and the P3 component. Given similarities between the time course and topography of the prospective positivity and P3 component, one might wonder whether the prospective positivity reflects a general index of target categorization in prospective memory paradigms (West et al., 2003). To examine this question, West et al. (2006) examined the effects of working memory load on the amplitude of the prospective positivity and the P3 component. The logic of the study was this: If the prospective positivity and P3 arise from the activity of similar processes, then both should be sensitive to working memory load (Gevins et al., 1996); in contrast, if the prospective positivity and P3 reflect distinct processes, then there may be differential effects of working memory load on these two modulations of the ERPs. The data from this study support the latter hypothesis, as the amplitude of the P3 for target stimuli decreased with increasing working memory load (**Figure 5**), while the amplitude of the prospective positivity was unaffected by increasing working memory load (West and Bowry, 2005; West et al., 2006). These data demonstrate that that the neural correlates of prospective memory, in this case the prospective positivity, can be dissociated from processes that are more generally related to target categorization or selection.

Following from work examining the temporal dynamics of processes underlying prospective

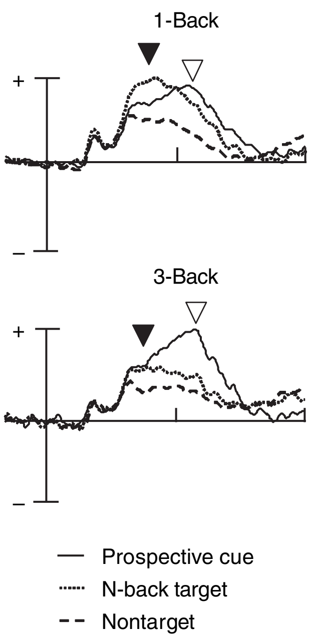


**Figure 5** Grand average ERPs for prospective cue, N-back target, and nontarget trials at electrode, Pz demonstrating the effect of N-back load on the P3, but not the prospective positivity. The filled arrow marks the P3, and the unfilled arrow marks the prospective positivity. Adapted from West R, Bowry R, and Krompinger J (2006) The effects of working memory demands on the neural correlates of prospective memory. *Neuropsychologia* 44: 197–207.

memory, other investigations have sought to determine whether modulations of the ERPs associated with the realization of delayed intentions possess the characteristics of cognitive processes described in theories of prospective memory. Two such studies have examined the influence of the working memory demands of the ongoing activity and strategic monitoring on the N300 (West et al., 2006; West, in press a). Based on strategic monitoring accounts of prospective memory, the amplitude of the N300 was expected to decrease as the working memory demands of the ongoing activity increased; in contrast, based on the discrepancy plus search account, the N300 was not expected to be sensitive to working memory load. The application of partial least squares analysis (McIntosh et al., 1996) – which allows one to decompose the effects of different experimental manipulations on the ERPs into a set of orthogonal latent variables – revealed that the N300 was expressed by two latent variables (West et al., 2006): one that was sensitive to N-back load and expressed the N300, but not the prospective positivity, and one that was insensitive to N-back load and expressed the N300 and prospective positivity. The results of this study reveal two important findings. First, consistent with the multiprocess view of prospective memory, these data reveal that both relatively automatic and more resource demands processes contribute to the detection of prospective cues. Second, these data reveal that the N300 and prospective positivity may be coupled to one another, a finding that is consistent with the general architecture of the discrepancy plus search theory (West, in press b).

## 2.45.10 Summary

Although ignored for many years, and indeed characterized as a forgotten topic 25 years ago (Harris, 1984, p. 71), research since that time has proven prospective memory to be an experimentally tractable and theoretically exciting area. Laboratory and nonlaboratory paradigms have been developed to examine prospective remembering under a variety of situations, and theoretical issues are stimulating rich understanding of the cognitive processes and neural mechanisms underlying prospective memory. Because the memory literature has focused on memory tasks in which experimenters initiate retrieval by putting subjects in a retrieval mode, it has ignored the important capability of humans to plan for future events and then later perform them in the appropriate circumstance. It appears that this self-initiated characteristic of prospective memory has important implications for considering optimal encoding, storage, and retrieval processes (see Ellis, 1996; Dobbs and Reeves, 1996). As our understanding of prospective memory has developed, and consistent with contextualistic views of memory (Jenkins, 1979), it also appears that prospective memory is not a unitary concept and, instead, that different processes are involved in different prospective memory tasks. We believe that it will be important, for both theoretical and applied concerns, to carefully examine these processes and the extent to which they are prominent in different prospective memory tasks.

## References


Anderson JR and Lebiere C (1998) *The Atomic Components of Thought*. Mahwah NJ: Erlbaum.

Baddeley A, Lewis V, Eldridge M, and Thosmson N (1984) Attention and retrieval from long-term memory. *J. Exp. Psychol. Gen.* 113: 518–540.

Bargh JA and Chartrand TL (1999) The unbearable automaticity of being. *Am. Psychol.* 54: 462–479.

Baumeister RF, Bratslavsky E, Muraven M, and Tice DM (1998) Ego depletion: Is the active self a limited resource? *J. Pers. Soc. Psychol.* 74: 1252–1265.

Bennett LR, Clawson DM, and Kardiasmenos KS (2005) The retrospective component of prospective memory: Relationship to prospective-component success. Poster presented at the 46th Annual Meeting of the Psychonomic Society Toronto ON.

Block RA and Zakay D (2006) Prospective remembering involves time estimation and memory processes. In: Glicksohn J and Myslobodsky MS (eds.) *Timing the Future: The Case for a Time-Based Prospective Memory*, pp. 25–49. London: World Scientific.

Bornstein BH and LeCompte DC (1995) A comparison of forgetting for source and item recognition. *Psychon. Bull. Rev.* 2: 254–259.

Brandimonte MA and Passolunghi MC (1994) The effect of cue-familiarity, cue-distinctiveness and retention interval on prospective remembering. *Q. J. Exp. Psychol. Hum. Exp. Psychol.* 47(A): 565–588.

Bravin JH, Kinsella GJ, Ong B, and Vowels L (2000) A study of performance of delayed intentions in multiple sclerosis. *J. Clin. Exp. Neuropsychol.* 22: 418–429.

Breneiser JE and McDaniel MA (2006) Discrepancy processes in prospective memory retrieval. *Psychon. Bull. Rev.* 13: 837–841.

Burgess PW, Veitch E, de Lacy Costello A, and Shallice T (2000) The cognitive and neuroanatomical correlates of multitasking. *Neuropsychologia* 38: 848–663.

Burgess PW, Quayle A, and Frith CD (2001) Brain regions involved in prospective memory as determined by positron emission tomography. *Neuropsychologia* 39: 545–555.

Burgess PW, Scott SK, and Frith CD (2003) The role of the rostral frontal cortex (area 10) in prospective memory: A lateral versus medial dissociation. *Neuropsychologia* 41: 906–918.

Burgess PW, Simons JS, Dumontheil I, and Gilbert SJ (2005) The gateway hypothesis of rostral prefrontal cortex (area 10) function. In: Duncan J, Phillips L, and McLeod P (eds.) *Measuring the Mind: Speed Control and Age*, pp. 217–248, Oxford: Oxford University Press.
Ceci SJ and Bronfenbrenner U (1985) ''Don't forget to take the cupcakes out of the oven'': Prospective memory, strategic time-monitoring and context. *Child Dev.* 56: 152–164.
Chasteen AL, Park DC, and Schwarz N (2001) Implementation intentions and facilitation of prospective memory. *Psychol. Sci.* 12: 457–461.
Cherry KE and LeCompte DC (1999) Age and individual differences influence prospective memory. *Psychol. Aging* 14: 60–76.
Cockburn J (1995) Task interruption in prospective memory: A frontal lobe function. *Cortex* 31: 87–97.
Cohen AL, and Gollwitzer PM (in press) The cost of remembering to remember: Cognitive load and implementation intentions influence ongoing task performance. In: Kliegel M, McDaniel MA, Einstein GO (eds.) *Prospective Memory: Cognitive, Neuroscience, Developmental and Applied Perspectives*, Mahwah NJ: Erlbaum.
Cook GI, Marsh RL, and Hicks JL (2005) Associating a time-based prospective memory task with an expected context can improve or impair intention completion. *App. Cogn. Psychol.* 19: 345–360.
Craik FIM (1986) A functional account of age differences in memory. In: Clix F and Hangendorf H (eds.) *Human Memory and Cognitive Capabilities: Mechanisms and Performances*, pp. 409–422. Amsterdam: Elsevier.
Craik FIM, Govoni R, Naveh-Benjamin M, and Anderson ND (1996) The effects of divided attention on encoding and retrieval processes in human memory. *J. Exp. Psychol. Gen.* 125: 159–180.
Crovitz HF and Daniel WF (1984) Measurements of everyday memory: Toward the prevention of forgetting. *Bull. Psychon. Soc.* 22: 413–414.
De Bruycker W, Verhoef B, d'Ydewalle G, and Orban GA (2005) *Brain Regions Associated with Retention and Retrieval in Event-Based Prospective Memory*. Paper presented at the Second International Conference on Prospective Memory Zurich Switzerland.
Dembitzer A and Lai EJ (2003) Retained surgical instrument. *N. Engl. J. Med.* 348–228.
Dismukes RK (in press) Prospective memory in aviation and everyday settings. In: Kliegel M, McDaniel MA, and Einstein GO (eds.) *Prospective Memory: Cognitive, Neuroscience, Developmental and Applied Perspectives*, Mahwah, NJ: Erlbaum.
Dobbs AR and Reeves MB (1996) Prospective memory: More than memory. In: Brandimonte M, Einstein G, and McDaniel M (eds.) *Prospective Memory: Theory and Applications*, pp. 199–226. Hillsdale, NJ: Erlbaum.
Driscoll I, McDaniel MA, and Guynn MJ (2005) Apolipoprotein E and prospective memory in normally aging adults. *Neuropsychology* 19: 28–34.
Einstein GO and McDaniel MA (1990) Normal aging and prospective memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 16: 717–726.
Einstein GO and McDaniel MA (1996) Retrieval processes in prospective memory: Theoretical approaches and some new empirical findings. In: Brandimonte M, Einstein GO, and McDaniel MA (eds.) *Prospective Memory: Theory and Applications*, pp. 115–142. Mahwah, NJ: Lawrence Erlbaum.
Einstein GO and McDaniel MA (2005) Prospective memory: Multiple retrieval processes. *Curr. Dir. Psychol. Sci.* 14: 286–290.
Einstein GO, McDaniel MA, Richardson SL, Guynn MJ, and Cunfer AR (1995) Aging and prospective memory: Examining the influences of self-initiated retrieval processes. *J. Exp. Psychol. Learn. Mem. Cogn.* 21: 996–1007.
Einstein GO, McDaniel MA, Smith RE, and Shaw P (1998) Habitual prospective memory and aging: Remembering intentions and forgetting actions. *Psychol. Sci.* 9: 284–288.
Einstein GO, McDaniel MA, Thomas R, et al. (2005) Multiple processes in prospective memory retrieval: Factors determining monitoring versus spontaneous retrieval. *J. Exp. Psychol. Gen.* 134: 327–342.
Einstein GO, McDaniel MA, Williford CL, Pagan JL, and Dismukes RK (2003) Forgetting of intentions in demanding situations is rapid. *J. Exp. Psychol. Appl.* 9: 147–162.
Einstein GO, Smith RE, McDaniel MA, and Shaw P (1997) Aging and prospective memory: The influence of increased task demands at encoding and retrieval. *Psychol. Aging* 12: 479–488.
Ellis J (1996) Prospective memory or the realization of delayed intentions: A conceptual framework for research. In: Brandimonte M, Einstein G, and McDaniel M (eds.) *Prospective Memory: Theory and Applications*, pp. 1–51. Hillsdale, NJ: Erlbaum.
Elvevag B, Maylor EA, and Gilbert AL (2003) Habitual prospective memory in schizophrenia. *BioMed Centr. Psychiatry* 3: 9. www.biomedcentral.com/1471: 244X/3/9.
Freeman JE and Ellis J (2003) The representation of delayed intentions: A prospective subject-performed task? *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 976–992.
Gevins A, Smith ME, Le J, et al. (1996) High resolution evoked potential imaging of the cortical dynamics of human working memory. *Electroencephalogr. Clin. Neurophysiol.* 98: 327–348.
Gollwitzer PM (1999) Implementation intentions: Strong effects of simple plans. *Am. Psychol.* 54: 493–503.
Goschke T and Kuhl J (1993) Representation of intentions: Persisting activation in memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 19(5): 1211–1226.
Guttentag RE (1984) The mental effort requirement of cumulative rehearsal: A developmental study. *J. Exp. Child Psychol.* 37: 92–106.
Guynn MJ (2003) A two-process model of strategic monitoring in event-based prospective memory: Activation/retrieval mode and checking. *Int. J. Psychol.* 38: 245–256.
Guynn MJ and McDaniel MA (2007) Target pre-exposure eliminates the effect of distraction on event-based prospective memory. *Psychon. Bull. Rev.* 14: 484–488.
Guynn MJ, McDaniel MA, and Einstein GO (1998) Prospective memory: When reminders fail. *Mem. Cogn.* 26: 287–298.
Guynn MJ, McDaniel MA, and Einstein GO (2001) Remembering to perform intentions: A different type of memory? In: Zimmer HD, Cohen RL, Guynn MJ, Engelkamp J, Kormi-Nouri R, and Foley MA (eds.) *Memory for Action: A Distinct Form of Episodic Memory?* pp. 25–48. Oxford: Oxford University Press.
Harris JE (1984) Remembering to do things: A forgotten topic. In: Harris JE and Morris PE (eds.) *Everyday Memory, Actions and Absent-Mindedness*, pp. 71–92. London: Academic Press.
Harris JE and Wilkins AJ (1982) Remember to do things: A theoretical framework and an illustrative experiment. *Hum. Learn.* 1: 123–136.
Heffernan TM, Jarvis H, Rodgers J, Scholey AB, and Ling J (2001) Prospective memory, everyday cognitive failures and central executive function in recreational users of Ecstasy. *Hum. Psychopharmacol. Clin. Exp.* 16: 607–612.
Henry JD, MacLeod MS, Phillips H, and Crawford JR (2004) A meta-analytic review of prospective memory and aging. *Psychol. Aging* 19(1): 27–39.
Hicks JL, Marsh RL, and Cook GI (2005) Task interference in time-based, event-based and dual intention prospective memory conditions. *J. Mem. Lang.* 53: 430–444.

Hicks JL, Marsh RL, and Russell EJ (2000) The properties of retention intervals and their affect on retaining prospective memories. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1160–1169.

Howard DC, McDaniel MA, and Butler KM (2006) *Implementation Intentions and Prospective Memory in Young Adults*. Paper presented at the Annual Meeting of the Psychonomic Society, Houston, TX.

Insel K, Morrow D, Brewer B, and Figueredo A (2006) Executive function, working memory and medication adherence among older adults. *J. Gerontol. Psychol. Sci.* 61(2): 102–107.

Jenkins JJ (1979) Four points to remember: A tetrahedral model of memory. In: Cermak LS and Craik FIM (eds.) *Levels of Processing in Human Memory*, pp. 429–446. Hillsdale NJ: Erlbaum.

Kardiasmenos KS, Clawson DM, Wilken JA, and Wallin MT (2004) *Effects of Implementation Intentions on Prospective Memory Performance*. Poster presented at the 45th Annual Meeting of the Psychonomic Society, Minneapolis, MN.

Katai S, Maruyama T, Hashimoto T, and Ikeda S (2003) Event based and time based prospective memory in Parkinson's disease. *J. Neurol. Neurosurg. Psychiatry* 74: 704–709.

Kliegel M, Eschen A, and Thone-Otto AI (2004) Planning and realization of complex intentions in traumatic brain injury and normal aging. *Brain Cogn.* 56: 43–54.

Kliegel M, Mackinlay R, and Jager T (in press) A lifespan approach to the development of complex prospective memory. In: Kliegel M, McDaniel MA, Einstein GO *Prospective Memory: Cognitive, Neuroscience, Developmental and Applied Perspectives*, Mahwah, NJ: Erlbaum.

Kliegel M, Phillips LH, Lemke U, and Kopp UA (2005) Planning and realisation of complex intentions in patients with Parkinson's disease. *J. Neurol. Neurosurg. Psychiatry* 76: 1501–1505.

Klein SB and Kilstrom JF (1986) Elaboration, organization and the self-reference effect in memory. *J. Exp. Psychology: Gen.* 115: 26–38.

Kok A (2001) On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology* 38: 557–577.

Kondel TK (2002) Prospective memory and executive function in schizophrenia. *Brain Cogn.* 2: 405–410.

Kumar D, Nizamie HS, and Jahan M (2005) Event-based prospective memory in schizophrenia. *J. Clin. Exp. Neuropsychol.* 27: 867–872.

Kvavilashvili L and Fisher L (2007) Is time-based prospective remembering mediated by self-initiated rehearsals? Role of incidental cues, ongoing activity, age and motivation. *J. Exp. Psychol. Gen.* 136: 112–132.

Kvavilashvili L, Kyle F, and Messer DJ (in press) The development of prospective memory in children: Methodological issues, empirical findings and future directions. In: Kliegel M, McDaniel MA, Einstein GO (eds.) *Prospective Memory: Cognitive, Neuroscience, Developmental and Applied Perspectives*, Mahwah, NJ: Erlbaum.

Kvavilashvili L, Messer DJ, and Ebdon P (2001) Prospective memory in children: The effects of age and task interruption. *Dev. Psychol.* 37: 418–430.

Lebiere C and Lee FJ (2002) Intention superiority effect: A context-switching account. *Cogn Sys Res* 3: 57–65.

Mäntylä T (1994) Remembering to remember: Adult age differences in prospective memory. *J. Gerontol.* 49: 276–282.

Marsh RL, Cook GI, and Hicks JL (2006a) An analysis of prospective memory. In: Ross BH (ed.) *The Psychology of Learning and Motivation*, vol. 46, pp. 115–153. San Diego: Academic Press.

Marsh RL, Cook GI, Meeks JT, Clark-Foos A, and Hicks JL (2007) Memory for intention-related material presented in a channel. *Mem. Cogn.* 5: 1197–1204.

Marsh RL, Hancock TW, and Hicks JL (2002a) The demands of an ongoing activity influence the success of event-based prospective memory. *Psychon. Bull. Rev.* 9: 604–610.

Marsh RL and Hicks JL (1998) Event-based prospective memory and executive control of working memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 24: 336–349.

Marsh RL, Hicks JL, and Bink ML (1998a) Activation of completed, uncompleted and partially completed intentions. *J. Exp. Psychol. Learn. Mem. Cogn.* 24: 350–361.

Marsh RL, Hicks JL, and Bryan ES (1999) The activation of unrelated and cancelled intentions. *Mem. Cogn.* 27: 320–327.

Marsh RL, Hicks JL, and Cook GI (2005) On the relationship between effort toward an ongoing task and cue detection in event-based prospective memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 861–870.

Marsh RL, Hicks JL, and Cook GI (2006b) Task interference from prospective memories covaries with contextual associations of fulfilling them. *Mem. Cogn.* 34: 1037–1045.

Marsh RL, Hicks JL, Cook GI, Hansen JS, and Pallos AL (2003) Interference to ongoing activities covaries with the characteristics of an event-based intention. *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 861–870.

Marsh RL, Hicks JL, and Hancock TW (2000) On the interaction of ongoing cognitive activity and the nature of event-based intention. *Appl. Cogn. Psychol.* 14: 529–541.

Marsh RL, Hicks JL, and Landau JD (1998b) An investigation of everyday prospective memory. *Mem. Cogn.* 26: 633–643.

Marsh RL, Hicks JL, and Watson V (2002b) The dynamics of intention retrieval and coordination of action in event-based prospective memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 28: 652–660.

Mathias JL and Mansfield KM (2005) Prospective and declarative memory problems following moderate and severe traumatic brain injury. *Brain Inj.* 19: 271–282.

Matthews RD (1992) *Are Retrospective and Prospective Memory Related?* Master's Thesis, University of North Carolina Greensboro.

Maylor EA (1990) Age and prospective memory. *Q. J. Exp. Psychol.* 42A: 471–493.

Maylor EA (1996) Age-related impairment in an event-based prospective memory task. *Psychol. Aging* 11: 74–78.

Maylor EA, Darby RJ, and Della Salla S (2000) Retrieval of performed versus to-be-performed tasks: A naturalistic study of the intention superiority effect in normal aging and dementia. *Appl. Cogn. Psychol.* 14: S83–S98.

McCauley SR and Levin HS (2004) Prospective memory in pediatric traumatic brain injury: A preliminary study. *Dev. Neuropsychol.* 25: 5–20.

McDaniel MA and Einstein GO (1993) The importance of cue familiarity and cue distinctiveness in prospective memory. *Memory* 1: 23–41.

McDaniel MA and Einstein GO (2000) Strategic and automatic processes in prospective memory retrieval: A multiprocess framework. *Appl. Cogn. Psychol.* 14: S127–S144.

McDaniel MA and Einstein GO (2007) *Prospective Memory: An Overview and Synthesis of an Emerging Field*. Thousand Oaks, CA: Sage.

McDaniel MA and Einstein GO (eds.) (2007) *Prospective Memory: Cognitive, Neuroscience, Developmental and Applied Perspectives.* Mahwah, NJ: Erlbaum.

McDaniel MA, Einstein GO, and Jacoby LL (2007) New considerations in aging and memory: The glass may be half full. In: Craik FIM and Salthouse TA (eds.) *The Handbook of Aging and Cognition*, pp. 251–310, 3rd edn. Mahwah, NJ: Erlbaum.

McDaniel MA, Einstein GO, and Rendell PG (in press) The puzzle of inconsistent age-related declines in prospective memory: A multiprocess explanation. In: Kliegel M, McDaniel MA, and Einstein GO (eds.) *Prospective Memory: Cognitive, Neuroscience, Developmental and Applied Perspectives*. Mahwah, NJ: Erlbaum.

McDaniel MA, Einstein GO, Stout AC, and Morgan Z (2003) Aging and maintaining intentions over delays: Do it or lose it. *Psychol. Aging* 18(4): 807–822.

McDaniel MA, Guynn MJ, Einstein GO, and Breneiser JE (2004) Cue focused and automatic-associative processes in prospective memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 605–614.

McDaniel MA and Pressley M (1987) *Imagery and Related Mnemonic Processes: Theories, Individual Differences and Applications*. New York: Springer.

McDaniel MA, Robinson-Riegler B, and Einstein GO (1998) Prospective remembering: Perceptually driven or conceptually driven processes? *Mem. Cogn.* 26: 121–134.

McGann D, Defeyter MA, Ellis JA, and Reid C (2005) *Prospective memory in children: The effects of age and target salience*. Paper presented at the 2nd International Prospective Memory Conference, Zurich, Switzerland.

McIntosh AR, Bookstein FL, Haxby JV, and Grady CL (1996) Spatial pattern analysis of functional images using partial least squares. *Neuroimage* 3: 143–157.

Meacham JA and Singer J (1977) Incentive effects in prospective remembering. *J. Psychol. Interdiscipl. Appl.* 97: 191–197.

Morrell RW, Park DC, Kidder DP, and Martin M (1997) Adherence to antihypertensive medications across the life span. *Gerontologist* 37: 609–619.

Morris CD, Bransford JD, and Franks JJ (1977) Levels of processing versus transfer appropriate processing. *J. Verb. Learn. Verb. Behav.* 16: 519–533.

Moscovitch M (1994) Memory and working with memory: Evaluation of a component process model and comparisons with other models. In: Schacter DL and Tulving E (eds.) *Memory Systems*, pp. 269–310. Cambridge, MA: MIT Press.

Nowinski JL, Holbrook JB, and Dismukes RK (2003) Human memory and cockpit operations: An ASRS study. *Proceedings of the 12th International Symposium on Aviation psychology*, pp. 888–893. Dayton, OH: The Wright State University. Retrieved October 20, 2006, from http://human-factors.arc.nasa.gov/ihs/flightcognition/Publications/Nowinski_etal_ISAP03.pdf

Okuda J, Fujii T, Ohtake H, et al. (2001) Brain mechanisms underlying human prospective memory. In: Yamadori A, Kawashima R, Fujii T, and Suzuki K (eds.) *Frontiers in Human Memory*, pp. 79–96. Sendai, Japan: Tohoku University Press.

Okuda J, Fujii T, Yamadori A, et al. (1998) Participation of the prefrontal cortices in prospective memory: Evidence from a PET study in humans. *Neurosci. Lett.* 253: 127–130.

Palmer HM and McDonald S (2000) The role of frontal and temporal lobe processes in prospective memory. *Brain Cogn.* 44: 103–107.

Park DC, Hertzog C, Kidder DP, Morell RW, and Mayhorn CB (1997) Effect of age on event-based and time-based prospective memory. *Psychol. Aging* 12: 314–327.

Park DC and Kidder DP (1996) Prospective memory and medication adherence. In: Brandimonte M, Einstein GO, and McDaniel MA (eds.) *Prospective Memory: Theory and Applications*, pp. 1–22. Mahwah, NJ: Erlbaum.

Phillips LH, Henry JD, Martin M (in press) Adult aging and prospective memory: The importance of ecological validity. In: Kliegel M, McDaniel MA, Einstein GO (eds.) *Prospective Memory: Cognitive, Neuroscience, Developmental and Applied Perspectives*, Mahwah, NJ: Erlbaum.

Reason JT (1990) *Human Error*. Cambridge, MA: Cambridge University Press.

Reese CM (2004) *Age and Focal Processing in Event-Based Prospective Memory*. Paper presented at the Cognitive Aging Conference, Atlanta, GA.

Reese CM and Cherry KE (2002) The effects of age, ability and memory monitoring on prospective memory task performance. *Aging Neuropsychol. Cogn.* 9: 98–113.

Rendell PG, McDaniel MA, Forbes RD, and Einstein GO (2007) Age-related effects in prospective memory are modulated by ongoing task complexity and relation to target cue. *Aging Neuropsycho. Cogn.* 3: 236–256.

Reynolds J, West R, and Braver T (2003) Differentiation of prospective memory and working memory using a mixed state and event-related fMRI design. *J. Cogn. Neurosci. Suppl.* p. 147.

Ricaurte GA, Yuan J, Hatzidimitriou Cord BJ, and McCann UD (2002) Severe dopaminergic neurotoxicity in primates after a common recreational dose regimen of MDMA (''Ecstasy''). *Science* 297: 2260–2263.

Robinson-Riegler MB (1994) *The Recognition-Recall Hypothesis of Prospective Memory.* PhD Thesis, Purdue University.

Rugg MD (2004) Retrieval processes in human memory: Electrophysiological and fMRI evidence. In: Gazzaniga MS (ed.) *The Cognitive Neurosciences,* 3rd edn., pp. 727–737. Cambridge MA: MIT Press.

Schaeffer EG, Kozak MV, and Sagness K (1998) The role of enactment in prospective remembering. *Mem. Cogn.* 26: 644–650.

Shallice T and Burgess P (1991) Deficits in strategy application following frontal lobe damage in man. *Brain* 114: 727–741.

Schmitter-Edgecombe M and Wright MJ (2004) Event-based prospective memory following severe closed-head injury. *Neuropsychology* 18: 353–361.

Sellen AJ, Louie G, Harris JE, and Wilkins AJ (1997) What brings intentions to mind? An *in situ* study of prospective memory. *Memory* 5: 483–507.

Shum D, Ungvari GS, Tang W-K, and Leung JP (2004) Performance of schizophrenia patients on time-, event- and activity-based prospective memory tasks. *Schizophr. Bull.* 30: 693–701.

Shum D, Valentine M, and Cutmore T (1999) Performance of individuals with severe long-term traumatic brain injury on time-, event- and activity-based prospective memory tasks. *J. Clin. Exp. Neuropsychol.* 21: 49–58.

Simons JS, Schölvinck ML, Gilbert SJ, Frith CD, and Burgess PW (2006) Differential components of prospective memory? Evidence from fMRI. *Neuropsychologia* 44: 1388–1397.

Singer JJ, Falchi M, MacGregor AJ, Cherkas LF, and Spector TD (2006) Genome-wide scan for prospective memory suggests linkage to chromosome 12q22. *Behav. Genet.* 36: 18–28.

Smith RE (2003) The cost of remembering to remember in event-based prospective memory: Investigating the capacity demands of delayed intention performance. *J. Exp. Psychol. Learn. Mem. Cogn.* 29: 347–361.

Smith RE and Bayen UJ (2004) A multinomial model of event-based prospective memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 30: 756–777.

Smith RE and Bayen UJ (2006) The source of adult age differences in event-based prospective memory: A multinomial model approach. *J. Exp. Psychol. Learn. Mem. Cogn.* 32: 623–635.

Somerville SC, Wellman HM, and Cultice JC (1983) Young children's deliberate reminding. *J. Genet. Psychol.* 143: 87–96.

Stokes S, Pierroutsakos S, and Einstein G (2007) *Remembering to Remember: Strategic and Spontaneous Processes in*

*Children's Prospective Memory*. Paper presented at the Meeting of the Society for Research in Child Development, Boston, MA.
Tulving E (1983) *Elements of Episodic Memory*. New York: Oxford University Press.
Tulving E (2004) *Memory, Consciousness and Time*. Keynote address presented at the 16th Annual Convention of the American Psychological Society, Chicago, IL.
West RL (1988) Prospective memory and aging. In: Gruneberg MM, Morris PE, and Sykes RN (eds.) *Practical Aspects of Memory*, vol. 2, pp. 119–125. Chichester, UK: Wiley.
West R (2005) The neural basis of age-related decline in prospective memory. In: Cabeza R, Nyberg L, and Park D (eds.) *Cognitive Neuroscience of Aging*, pp. 246–264. New York: Oxford University Press.
West R (in press a) Towards a cognitive neuroscience of prospective memory. In: Kliegel M, McDaniel MA, and Einstein GO (eds.) *Prospective Memory: Cognitive Neuroscience Developmental and Applied Perspectives*. Mahwah, NJ: Erlbaum
West R (in press b) The influence of strategic monitoring on the neural correlates of prospective memory. *Mem. Cogn.*
West R and Bowry R (2005) Effects of aging and working memory demands on prospective memory. *Psychophysiology* 42: 698–712.
West R, Bowry R, and Krompinger J (2006) The effects of working memory demands on the neural correlates of prospective memory. *Neuropsychologia* 44: 197–207.
West R and Craik FIM (1999) Age-related decline in prospective memory: The roles of cue accessibility and cue sensitivity. *Psychol. Aging* 14: 264–272.
West R and Craik FIM (2001) Influences on the efficiency of prospective memory in younger and older adults. *Psychol. Aging* 16: 682–696.
West R and Covell E (2001) Effects of aging on event-related neural activity related to prospective remembering. *Neuroreport* 12: 2855–2858.
West R, Herndon RW, and Crewdson SJ (2001) Neural activity associated with the realization of a delayed intention. *Cogn. Brain Res.* 12: 1–10.
West R and Krompinger J (2005) Neural correlates of prospective and episodic memory. *Neuropsychologia* 43: 418–433.
West R, Krompinger J, and Bowry R (2005) Disruptions of preparatory attention contribute to failures of prospective memory. *Psychon. Bull. Rev.* 12: 502–507.
West R and Ross-Munroe K (2002) Neural correlates of the formation and realization of delayed intentions. *Cogn. Affect. Behav. Neurosci.* 2: 162–173.
West R and Wymbs N (2004) Is detecting prospective cues the same as selecting targets? An ERP study. *Cogn. Affective Behav. Neurosci.* 4: 354–363.
West R, Wymbs N, Jakubek K, and Herndon RW (2003) Effects of intention load and background context on prospective remembering: An event-related brain potential study. *Psychophysiology* 40: 260–276.
Whittlesea BWA and Williams LD (2001a) The discrepancy-attribution hypothesis: I. The heuristic basis of feelings of familiarity. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 3–13.
Whittlesea BWA and Williams LD (2001b) The discrepancy-attribution hypothesis: II. Expectation, uncertainty, surprise and feelings of familiarity. *J. Exp. Psychol. Learn. Mem. Cogn.* 27: 14–33.
Wilson EAH and Park D (in press) Prospective memory and health behaviors: Context trumps cognition. In: Kliegel M, McDaniel MA, Einstein GO (eds.) *Prospective Memory: Cognitive, Neuroscience, Developmental and Applied Perspectives*, Mahwah, NJ: Erlbaum.
Zakzanis KK, Young DA, and Campbell Z (2003) Prospective memory impairment in abstinent MDMA (''Ecstasy'') users. *Cogn. Neuropsychiatry* 8: 141–153.

# 2.46 Autobiographical Memory

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## 2.46.1 Introduction

The term autobiographical memory refers to our memory for specific episodes, episodic memory, and to our conceptual, generic, and schematic knowledge of our lives, autobiographical knowledge. Typically these two types of long-term memory representation are brought together in an act of remembering where they form a specific memory. Consider the following example:

> My earliest memories relate to a time in my childhood when we were living in Malta. I was about four years old. We lived in the most glorious Italian house on the sea which had a great big flagstone hall and shutters looking out to the sea and a sweeping staircase that led up to the first floor and, I think this is true, but it seems wrong somehow because my parents were very kind to me. I remember having to stand looking at the wall halfway up the stairs because I couldn't remember the days of the week and I was taught them with reference to the gods, you know, Thor's day, Woden's day and so forth, and that I remember very vividly. One lunchtime I was asked to repeat them and I couldn't remember them and my father told me to go and stand halfway up this great big sweeping staircase and just look at the wall. (Taken from the BBC Radio 4 Memory Survey, July 2006, which collected 11,000 memories from the general public.)

There are various segments of autobiographical knowledge in this memory, e.g., when we lived in Malta, my parents were kind to me, some generic visual imagery, e.g., how various features of the house looked, and some highly specific knowledge of time, locations, and actions. Autobiographical memories very frequently come to mind as these compilations of different types of knowledge are configured into a memory in a specific act of remembering. As such they clearly illustrate the highly constructive nature of autobiographical remembering. We will return to memory construction in a later section, but now that we have some idea of what is meant by the term autobiographical memory, we might ask about how it has been studied. After all, autobiographical memories are personally important memory representations. They are the content of the self and define who we are, who we have been, and, importantly, who we can yet become. They enable us to have a past, present, and future in which we exist as individuals. They are, therefore, one of our most important bodies of knowledge and because of that would have been, it might be thought, the focus of memory research for many decades.

## 2.46.2 A Brief Biography of Autobiographical Memory Research

Remarkably, however, the study of autobiographical memory has mainly taken place over the last 2 decades, whereas as the formal scientific study of memory itself is at least over a century old, dating, arguably, to the seminal work of Herman Ebbinghaus (1885). Ebbinghaus famously studied memory for relatively meaningless items, such as short lists of constant-vowel-constant (CVC) letter strings. Less well known is that he also studied memory for meaningful materials such as passages of prose, poetry, etc. Ebbinghaus concluded that memory for these latter materials was influenced by too many factors beyond the experimenter's control and because of this the scientific or experimental study of memory would be more surely advanced using materials that the experimenter had powerful control over, such as CVC strings. Ebbinghaus's view held sway and the experimental study of memory in the laboratory has generally used to-be-remembered materials generated and controlled by the experimenter. Almost by definition this excludes autobiographical memories, as these are formed outside the laboratory in our everyday lives in response to complicated meaningful experiences – experiences over which the experimenter has no control.

Given the dominance of experimental studies of memory, it is perhaps not so surprising that it is only in relatively recent times that autobiographical memory has received any attention at all. According to one view, science moves from the simple to the complex and perhaps it was the case that some understanding of memory, deriving from experimental studies, had to be attained before the field could grapple with the complexities of autobiographical memory and the inevitable role in memory of mysterious entities such as the self, goals, and emotion. There is no doubt some truth in this but, as with all history including personal history, the story is more complicated. So, for instance, at the time Ebbinghaus was writing his field-defining book, another great nineteenth-century scientist, Sir Francis Galton (1883), was reporting his seminal work into memory. One aspect of this research focused on the recall of autobiographical memories. Galton was interested in how many memories we have and developed a technique that 100 years later became known as the cue word technique. In this procedure, Galton revealed to himself, one at a time, words he had previously arranged into an alphabetical list. In response to each word, he noted what thoughts passed through his mind. So when reading abasement, abhorrence, etc. (remember this was Victorian England), he would write out his thoughts. He carried out this procedure for the fairly long list of words on several separate occasions. There were a wide range of findings but one striking outcome was that many of his thoughts were (autobiographical) memories and they often came to mind in the form of visual mental images. Galton was rather disappointed to discover that there was not an endless variety in his thoughts or memories and that he often recalled the same thoughts/memories on subsequent occasions of testing. He concluded that we probably have far fewer memories than we imagine we have – about 6500 according to one researcher who tried to recall all her memories (Smith, 1952).

An obvious problem with Galton's method is that once a subject has recalled a memory, then that memory became associated with the cue word and as such was much more likely to be recalled on subsequent occasions. If so, then Galton may well have underestimated the extent of his autobiographical memories. Nonetheless, the cue word method has proved especially useful in more contemporary studies of autobiographical memory and Galton's original work remains a rewarding read for memory researchers, as does Ebbinghaus's important book.

Another book from this period that remains significant is Theodore Ribot's (1882) classic case studies of memory distortions and malfunction following brain injury. This work also contains one of the first theories of autobiographical memory and is worth consulting for that alone. Other memory researchers from the late nineteenth century also studied autobiographical memory (see Conway, 1990, 2004, for reviews), and among them Henri and Henri (1896, 1898) conducted the first autobiographical memory survey. However, psychology came to be dominated by behaviorism, at the heart of which was the belief that all psychological theory should be built upon that which was observable. As memories are internal mental states, they cannot be studied by direct observation but can only be inferred by their effects upon behavior, i.e., upon what can be recalled in an experiment where the conditions of learning, retention, and remembering are highly controlled. This approach became known as verbal learning. Indeed, the dominant journal in the area was called the *Journal of Verbal Learning and Verbal Behavior* (renamed in the 1980s the *Journal of Memory and Language*). For many decades, verbal learning dominated memory research and in many respects still does. A lone voice during this period was the British researcher Sir Fredrick Bartlett, whose famous book *Remembering: A Study in Experimental and Social Psychology* (1932) is generally credited with having created and maintained a different tradition in memory research. In this tradition, the concept of a schema (some sort of general representation of similar experiences, narrative, and cultural conventions) was central and social interactions and culture played important roles in remembering. Bartlett was, however, largely uninterested in detailed memories of specific experiences – what we now call episodic memories. Because of this, his work did not reinvigorate the study of autobiographical memory.

Instead the reemergence of the study of autobiographical memory after 100 years of silence (Cohen, 1989) started to take place in the 1970s and gathered pace in the 1980s. **Figure 1** shows the cumulative frequency of papers, by year since 1970, that have used the phrase autobiographical memory. This admittedly is a crude index of research activity into the topic, but as crude as it is, it nonetheless depicts very strikingly how autobiographical memory research has rapidly increased and developed in the last 35 years. So what happened to end the century of silence? There were, arguably, two main forces that led to renewed interest in this important aspect of memory. The first was the gradual emergence of neuropsychology as a distinct research area and within it the study of malfunctions of human memory following brain damage. One of the striking symptoms of patients with memory impairments caused by brain damage is that they virtually always have disrupted autobiographical memory. In a particularly important paper Crovitz and Schiffman (1974) reintroduced the Galton cue word method as a way of eliciting autobiographical memories in normal populations and later in patients with closed head injuries suffering from various degrees of amnesia, thus simultaneously rediscovering both Galton and Ribot. The second force was the developing interest within cognitive science in how to model and represent stories and memories. An important paper here that demonstrated how autobiographical memory might be studied under laboratory conditions was that of Robinson (1976), who also used the cue word method to investigate differences between memories with different types of affect. Add to this Brown and Kulik's (1977) original survey of flashbulb memories, a rather timely reminder from Neisser (1978) about the narrowness of memory research in the 1970s and preceding decades, and the highly significant volume edited by Neisser (1982), *Memory Observed*, which reprinted many of the papers of earlier researchers on autobiographical memory and other then-neglected areas of memory, and a strong impetus was in place to rejuvenate research into autobiographical memory. It is, perhaps, important to note that the renewed interest, reflected in **Figure 1**, had its roots in a rediscovery of the original work of Galton, Ribot, and others (see too Rapaport, 1950, for an especially interesting review of emotion and memory). It might be noted that the methods used by these early researchers – studying one's own memory, investigating malfunctions and distortions of memories, and surveying memories – also re-emerged in the contemporary study of autobiographical memory, and it is to the findings of these more recent studies we now turn.

## 2.46.3 The Representation of Autobiographical Knowledge in Long-Term Memory

This section reviews current thinking about the nature of autobiographical knowledge. It is important

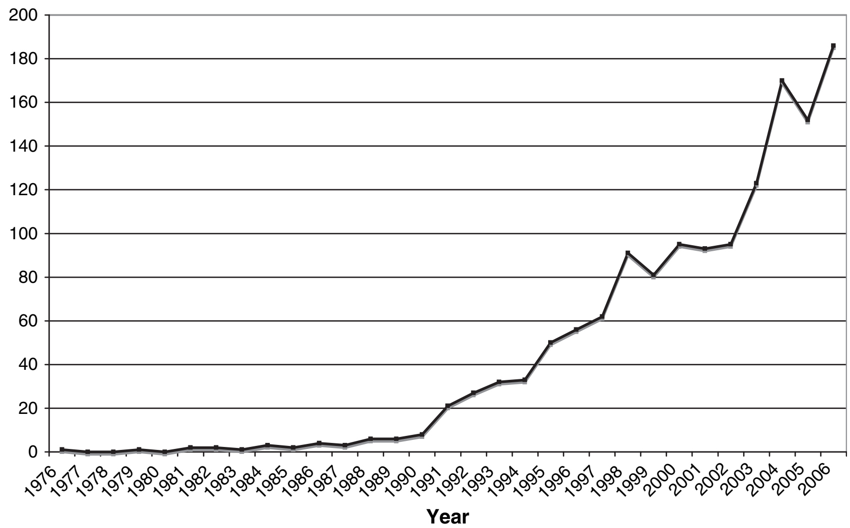


**Figure 1** Frequency of articles or research reviews published using the term autobiographical memory in the article title, abstract, or key words from 1970 to 2006. Data obtained from ISI Web of Knowledge, January 2007.

to note that a full review of findings is not undertaken here and instead only main findings and their implications are considered. One current model proposes that autobiographical memories are generated in the self-memory system or SMS (Conway and Pleydell-Pearce, 2000). Very briefly, the SMS is considered to be a virtual memory system consisting of a temporary interaction between control or executive processing systems with a complex multilayered long-term memory knowledge base. Another way to conceive of this is as an interaction between currently active, dynamic, or fluid aspects of the self with more permanent, long-term, or crystallized representations of the self and attributes of the self. The dynamic or executive aspect of the self is termed the working self. The working self consists of a complex hierarchy of currently active goals (Conway and Pleydell-Pearce, 2000) through which memories are encoded and retrieved. The working self also contains what Conway et al. (2004) termed the conceptual self, which in turn consists of beliefs, evaluations, and currently active self-images of what the self has been in the past, currently is considered to be, and what it may become in the future.

The working self regulates the construction of new memories in the SMS, at both encoding and during retrieval, by controlling access to the autobiographical memory knowledge base. **Figure 2** illustrates this relation between the working self and the knowledge base. The working self modulates memory by controlling the cues that are used to activate knowledge in the knowledge base. This is achieved by shaping cues so that particular types of information are activated. For example, a person asked to recall a memory of childhood might recall their earliest memory. Thus, elaborating the cue from 'recall a memory from childhood' into the cue 'recall my earliest memory.' This elaboration may take place several times as a cue is fine-tuned to access the information sought. An idea central to the SMS model is that specific autobiographical memories are formed when stable patterns of activation exist over interconnected representations of autobiographical knowledge and associated episodic memories. Thus, when conceptual and generic knowledge of the attributes of a house one lived in as a child, the relationship one had with one's parents, and a specific (episodic) memory of a moment in time are all activated together and interlinked, then the rememberer has the experience of remembering and their consciousness is dominated by a specific memory – as in the example we started with. It is these different types of autobiographical knowledge and their organization in long-term memory that we are concerned with next and we return to considering the process of constructing memories in a subsequent section.

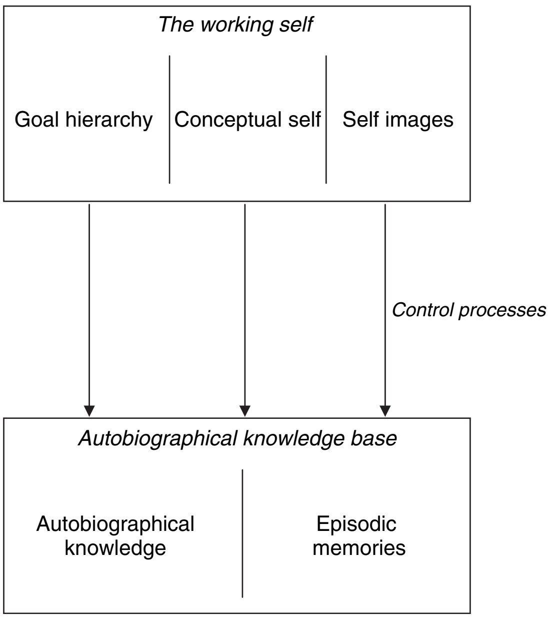


**Figure 2** The relationship between the working self and the autobiographical knowledge base.

According to the SMS model, long-term memory contains two distinct types of autobiographical representation: autobiographical knowledge and episodic memories. Autobiographical knowledge is organized in partonomic hierarchical knowledge structures (Conway and Bekerian, 1987; Barsalou, 1988; Conway, 1993, 1996; Lancaster and Barsalou, 1997; Burt et al. 2003) that range from highly abstract and conceptual knowledge (such as that contained in the conceptual self) to conceptual knowledge that is event-specific and experience-near. Autobiographical memory knowledge structures terminate in episodic memories, the second type of autobiographical representation contained in the autobiographical knowledge base. **Figure 3** illustrates how these complex autobiographical memory knowledge structures might be represented in long-term memory.

The upper part of **Figure 3** focuses on autobiographical knowledge and specifically on the life story, lifetime periods, and general events (Conway, 2005). These divisions of autobiographical knowledge are on a dimension of specificity, and at the most abstract level is a structure termed the life story

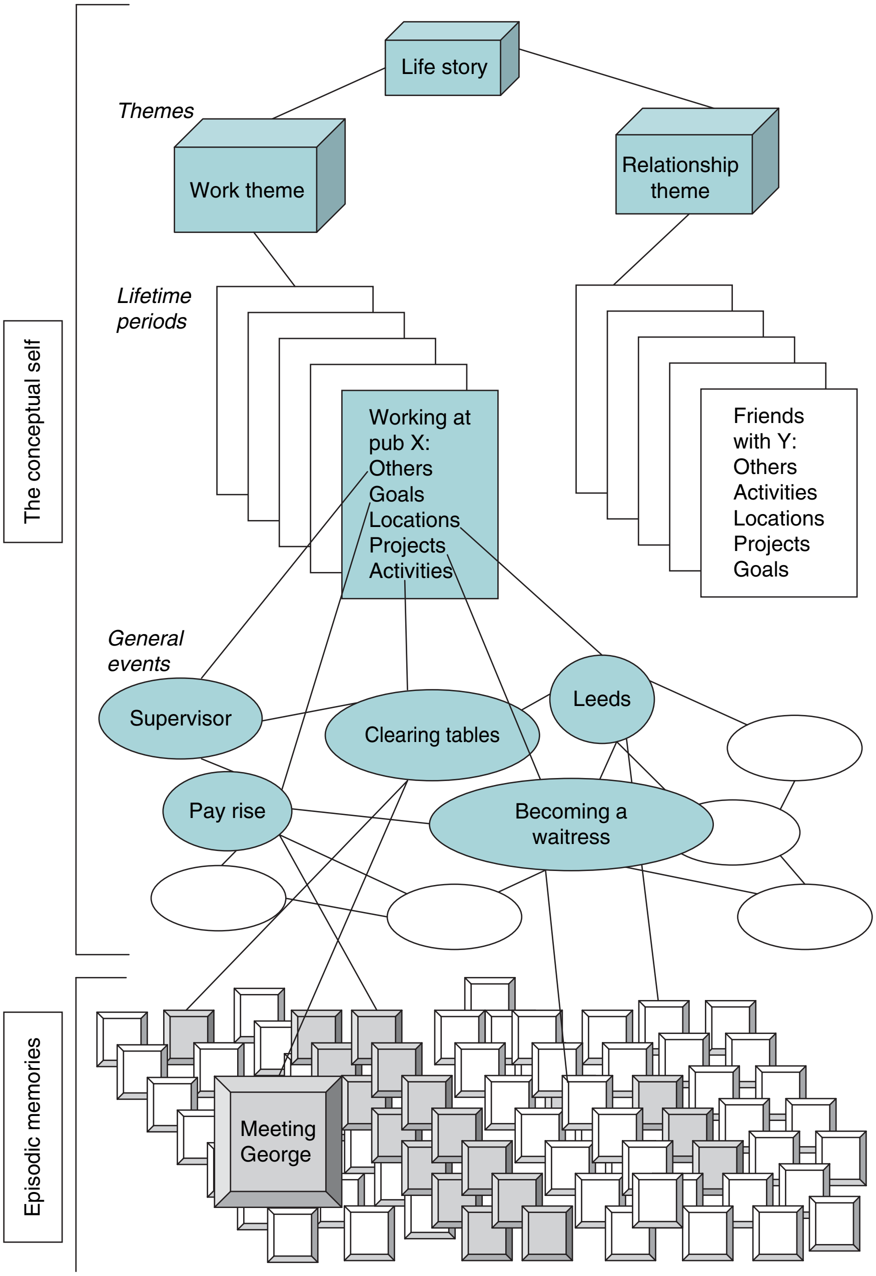


**Figure 3** Knowledge structures in autobiographical memory. Adapted from Conway MA (2005) Memory and the self. *J. Mem. Lang.* 53(4): 594–628.

(Pillemer, 1998; Bluck and Habermas, 2001; Bluck, 2003). The life story contains general factual and evaluative knowledge about the individual. It may also contain self-images that divide and separate the self into several different selves. It is represented in more or less coherent sets of themes that characterize, identify, and give meaning to a whole life (Bluck and Habermas, 2000, 2001). Divisions in the life story may be supported by the way in which different self-images contain cues that differentially access other knowledge in the autobiographical knowledge base. For example, a self that accesses a particular lifetime period (see **Figure 3**) will have cues that are channeled by knowledge represented as part of the lifetime period, which in turn can be used to access particular sets of general events that contain cues to specific episodic memories. It in this way that a memory can be gradually formed or constructed.

Lifetime periods contain representations of locations, people, activities, feelings, and goals common to the period they represent. They effectively encapsulate a period in memory and in so doing provide further ways in which access to autobiographical knowledge is channeled, or directed. Lifetime periods have been found to contain evaluative knowledge, negative and positive, of progress in goal attainment (Beike and Landoll, 2000), and lifetime periods may play an important role in the life story. For instance, lifetime periods may provide autobiographical knowledge that can be used to form life story schema and thus support the generation of themes. Lifetime periods may be particularly appropriate for this because of the goal-evaluative information they contain. For example, a lifetime period such as 'when I was at university,' will consist of representations of people, locations, activities, feelings, and goals common to the period but will also contain some general evaluation of the period, i.e., this was an anxious time for me, living away from home was difficult, I was lonely, I found the work too difficult, etc. (see Cantor and Kihlstrom, 1985).

The life story and lifetime periods are part of the conceptual self where they represent a summary account of the self and its history, and where they can be used to initiate and focus searches of the autobiographical knowledge base. General events, on the other hand, are more clearly part of the knowledge base itself and have been found to play important roles in organizing personal knowledge. General events are more strongly event-specific than lifetime periods but not as event-specific as sensory-perceptual episodic memories, which are directly derived from actual experience (Conway, 2001, 2005). General events refer to a variety of autobiographical knowledge structures such as single events, e.g., the day we went to London; repeated events, e.g., work meetings; and extended events, e.g., our holiday in Spain (Barsalou, 1988). General events are organized in several different ways. For example, they can take the form of mini-histories structured around detailed and sometimes vivid episodic memories of goal attainment in developing skills, knowledge, and personal relationships (Robinson, 1992). Some general events may be of experiences of particular significance for the self and act as reference points for other associated general events (Singer and Salovey, 1993; Pillemer, 1998). Yet other general events may be grouped together because of their emotional similarity (McAdams et al., 2001), and it is likely that there are yet other forms of organization at this level which await investigation(see for example, Brown and Schopflocher, 1998). However, the research currently available indicates that organization of autobiographical knowledge at the level of general events is extensive and it appears to virtually always refer to progress in the attainment of highly self-relevant goals. General event knowledge then represents information highly relevant to the goal hierarchy of the working self.

In one study of this type of knowledge, Robinson (1992) examined people's memories for the acquisition of skills, e.g., riding a bicycle, driving a car, and for aspects of personal relationships. These general events were found to be organized around sets of vivid memories relating to goal attainment. Consider two examples from Robinson's study:

> Ever agreeable, and eager to do anything that would get me out of the doldrums of inferiority, my father rented a bike and undertook to help me to learn to ride it. I shall always remember those first few glorious seconds when I realized I was riding on my own... (Quinn, 1990, cited in Robinson, 1992: 224.)

> The first time I flew an airplane was one of the best firsts. It marked a sense of accomplishment for myself, and it also started me on the career path I have always wanted to follow. The day was warm and hazy, much as summer days in Louisville are. My nervousness didn't help the situation, as I perspired profusely. But as we took off from runway 6 the feeling of total euphoria took over, and I was no longer nervous or afraid. We cruised at 2500 feet and I worked on some basic manoeuvres for approximately 45 minutes. We then returned to the airport, where I realized that this will soon be a career. (Robinson, 1992: 226.)

These first-time memories cue other related memories and the whole general event carries powerful self-defining evaluations that persist over long periods of time.

Relatively recent experiences, particularly those occurring during the current lifetime period, that give rise to sets of multiply related general events and associated episodic memories must be represented in terms of the currently active goals of the working self that dominate at the time. Burt et al. (2003) investigated this for several extended events, e.g., Christmas shopping. In these studies, events were sorted into groups by participants, and from these groupings currently active themes were identified. **Figure 4** shows the organization of a series of episodic memories associated

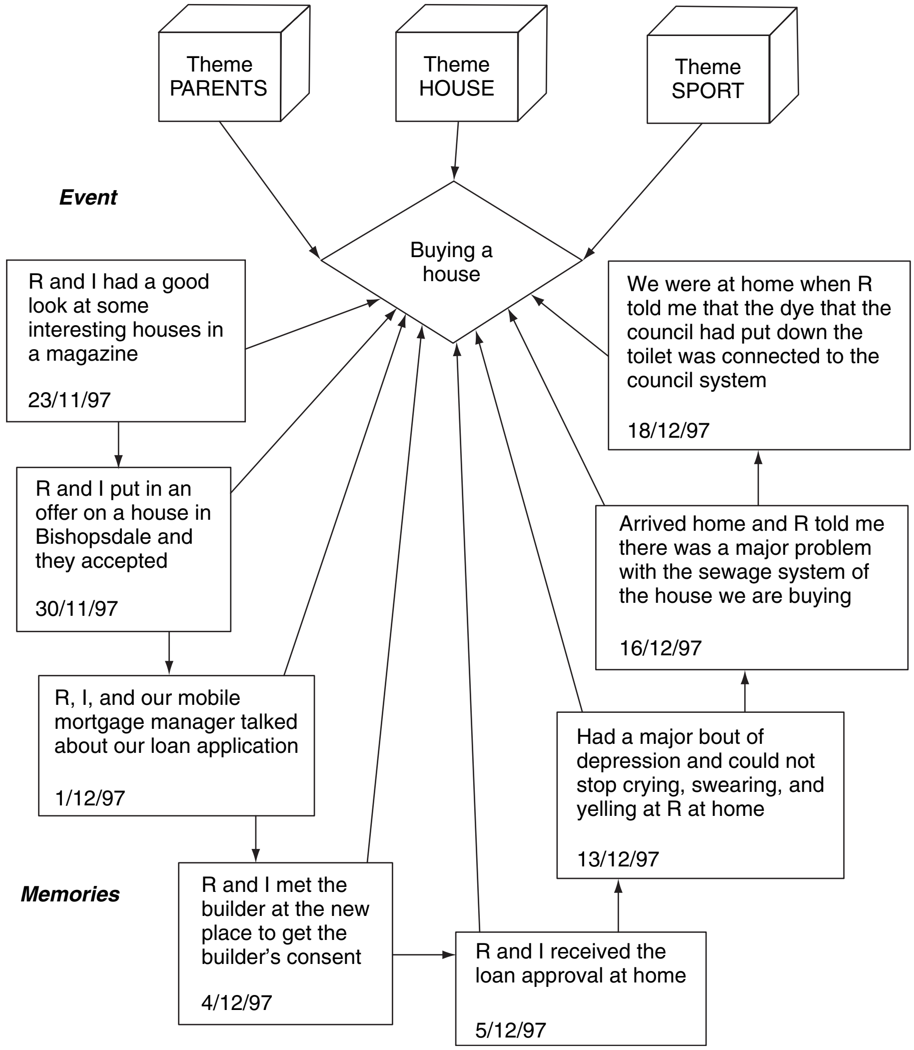


**Figure 4** Episodic memories associated with the general event of buying a house. From Burt CDB, Kemp S, and Conway MA (2003) Themes, events, and episodes in autobiographical memory. *Mem. Cogn.* 31: 317–325.

with the general event of buying a house (Burt et al., 2003). The themes shown in **Figure 4** are all associated with other memories as well and with lifetime periods in which the themes were present. The findings of Burt et al. (2003) demonstrate that general events typically access groups of episodic memories that connect the general event to unique and specific moments in time. One important property of this organization is that when goals change and new themes and lifetime periods become central to the working self, a record of the past concerns of an older version of the working self exists in the form of general events and the colonies of episodic memories they access. Thus, even if no goal information is explicitly encoded, it can, to at least some extent, be inferred from the groupings of general events and the associated episodic memories. Indeed, Robinson found that many memories featured goal-related evaluative knowledge or self-defining memories (Singer and Salovey, 1993) along with more general knowledge and specific episodic memories. General events provide, then, records of complicated and extended goal-related activities. These have powerful implications for the self, especially the conceptual self, and how a person evaluates their self.

## 2.46.4 Episodic Memory

So far we have been concerned with autobiographical knowledge, but specific autobiographical memories

**Table 1** Eight characteristics of episodic memory

| | |
|---|---|
| I | They retain summary records of sensory-perceptual-conceptual-affective processing derived from working memory. |
| II | They are predominantly represented in the form of (visual) images. |
| III | They represent short time slices, determined by changes in goal processing. |
| IV | They are only retained in a durable form if they become linked to conceptual autobiographical knowledge. Otherwise they are rapidly forgotten. |
| V | Their main function is to provide a short-term record of progress in current goal processing. |
| VI | They are recollectively experienced when accessed. |
| VII | When included as part of an autobiographical memory construction, they provide specificity. |
| VIII | Neuroanatomically they may be represented in brain regions separate from other (conceptual) autobiographical knowledge networks. |

consist of autobiographical knowledge and episodic memories. Episodic memories are, however, rather different types of representations. **Table 1** lists eight characteristics of episodic memories (from Conway, 2005, Table 4), and each of these is now considered in turn. The first three characteristics of episodic memories (numbered I, II, and III) in **Table 1** concern properties of episodic memories. First, the content of episodic memories is highly event-related and consists of detailed records of sensory-perceptual and conceptual-affective processing that was prominent during the original experience. Note that these are summary rather than literal representations, although they may occasionally contain some exact representations of processing that occurred during an experience (see the last paragraph of this section). Second, although they can, and indeed do, contain information from all the sensory modalities, they have been found to be predominantly visual in nature (see Brewer, 1988, for an interesting early study of the content of episodic memories). Finally they represent short time-slices of experience highly related to the moment-by-moment segmentation of experience into events (Williams et al., 2007b; Zacks et al., 2007).

Clearly, many episodic memories will be formed every day and simply casting one's mind back over the events of the day will bring to mind many highly detailed and specific episodic memories of events which occurred earlier in the day (see Williams et al., 2007b). In subsequent days, however, as the retention interval lengthens, many of these episodic memories, which are often of rather low self-relevance, routine events, become inaccessible. Even those that are retained over longer retention intervals are often not as detailed as they were close to the point of their formation. It has been suggested that only those episodic memories that are linked in some way to currently active goals become integrated with autobiographical knowledge in long-term memory. Episodic memories that become integrated in this way are retained over long retention intervals measured in months, years, decades, and even a lifetime (point IV in **Table 1**). Relatedly, the SMS model posits that one of the main functions of episodic memories is to provide a record of recent goal-processing episodes. Episodic memories provide a way in which to rapidly and effectively check that goal-related actions have been executed. They let the rememberer know that they did, for instance, lock the door, post the letter, have a coffee, and so on. If one of these routine events mapped onto an important goal or set of goals, then the episodic memory might become integrated with other knowledge in the autobiographical knowledge base and so become an enduring episodic memory. The study of self-defining experiences, the experience of trauma, and vivid memories generally provide many examples of how episodic memories become important parts of the autobiographical knowledge base, where they endure for many years (see Pillemer, 1998; Ehlers and Clark, 2000; Singer, 2005).

Points VI and VII in **Table 1** focus on another important aspect of episodic memories – that they are very highly associated with the experience of remembering. This is often referred to as recollective experience, and this and other forms of memory awareness have been the focus of many contemporary memory studies (see Tulving, 1985; Gardiner and Richardson-Klavehn, 2000, for reviews). Memory awareness in autobiographical remembering appears to be triggered or activated when an episodic memory enters conscious awareness (Conway, 2001, 2005), although it can also occur in other ways (cf. Moulin et al., 2005). Episodic memories, when they enter the construction of an autobiographical memory, cause the experience of remembering and also provided the constructed memory with specificity. As we will see, the specificity of the memory is important and is a quality that can be lost when memory malfunctions in, for example, psychological illness. Specificity provides a link to the experience of the world, and episodic memories are experience-near representations and stand in contrast to autobiographical and other conceptual knowledge which is experience-distant. Thus, the experience of remembering and memory specificity are important qualities of episodic memories. Finally, in **Table 1** (see VII), it is suggested that episodic memories might be represented in a separate brain region from more autobiographical conceptual knowledge (this is elaborated in Conway, 2005). We will return to this issue in the closing section of this chapter, but we might note here one general and intriguing finding that seems to support it: patients who suffer brain damage which has led to amnesia for much of their preinjury life, and especially amnesia for preinjury episodic memories, have nonetheless been found to retain often extensive autobiographical knowledge (Conway and Fthenaki, 2000).

## 2.46.5 Self-Defining Memories

The autobiographical knowledge base is complex and represents the personal history of an individual in different ways, i.e., as knowledge and as specific memories. Because of this complexity, the knowledge base is highly organized and some parts are more accessible than other parts. Generally, those autobiographical knowledge structures that are strongly associated with current goals and current images of the self are in a more accessible state than knowledge structures that are currently less self-relevant. In this section, we consider how the relation to the self can shape and organize autobiographical memory.

One important type of personal knowledge that appears to be highly accessible to the self is that of self-defining memories (SDMs). An SDM is a specific type of autobiographical memory that has the following attributes: affective intensity, vividness, high levels of rehearsal, linkage to similar memories, and connection to an enduring concern or unresolved conflict (Singer and Moffitt, 1991/1992; Singer and Salovey, 1993; Singer, 2005). Self-defining memories can be distinguished from other types of vivid memories. For example, flashbulb memories, as originally defined by Brown and Kulik (1977), are a particularly vivid and affective form of personal event memory (Pillemer, 1998), often about important public events. They have been found to be associated with four interrelated variables: surprise, consequentiality, importance, and emotion (Conway, 1995). Having these qualities does not necessarily indicate, however, that the memory is central to enduring goals of the self, and it is certainly possible to have highly vivid memories of events that are low in self-relevance (Conway et al., 2004). Importantly then, the two distinguishing criteria for self-defining memories that differentiate them from other vivid memories are, first, their linkage to other memories within the individual that share similar personal themes and, second, their relevance to the individual's enduring concerns or unresolved conflicts.

Both of these features – linkage of similar memories and relevance to concerns and conflicts – have been investigated in research into individuals' motivations and goals. For example, Thorne et al. (1998) looked at young adults' important relationship memories generated in two interviews over a 6-month period of time. Participants had freedom to describe similar or different relationship episodes in the second interview. Thorne et al. scored the memories for social motives for the memories that varied from time 1 to time 2, as well as the points of emphasis in the twice-told memories. For both unique memories and repeated memories, the authors found "moderate thematic consistency" (Thorne et al., 1998: 258), indicating that these memories, even when varying in content, reflected similar motivational themes and narrative structures. In a related study, Demorest and Alexander (1992) had raters code individuals' significant personal memories for overarching interpersonal scripts. A month later, these same individuals generated a set of fictional scenarios. Raters coded the themes of these scenarios and found striking overlap in terms of thematic continuity between the original memories and the imaginary stories. These results, along with those of Thorne et al. (1998), suggest that individuals link remembered and imagined experiences through personally significant themes. These themes originate, according to the SMS model, from the goals of the working self, but later can also serve to influence its ongoing goal processing.

Further evidence of the relationship of self-defining memories to individuals' enduring conflicts and concerns comes from the work of Singer and colleagues (Singer, 1990; Moffitt and Singer, 1994; Singer, 2005). These researchers found the affective quality of self-defining memories to be a function of the relevance of the memories to the attainment of a person's most desired goals. Moreover, this was found to be the case not only for memories relevant to the attainment of approach goals (desired goals), but also for memories about active efforts to avoid the consequences of undesired outcomes (Moffitt and Singer, 1994). Singer et al. (2002) additionally reported that the more personal growth students attributed to memories that grew out of community service experiences, the more likely these students were to place an overall emphasis on generative goal pursuits in their lives (see also de St. Aubin and McAdams, 1995). Similarly, in examining the relationship of turning-point and other significant personal memories to overall themes of the personality, McAdams (McAdams, 1982; McAdams et al., 1996) has consistently found power-oriented memories to be linked to agentic or individualistic motives, while intimacy-oriented memories reflected communal, social, and relationship motives. Jardine (1999) found that women counselors who experienced life transitions during their clinical training associated themes from their self-defining memories with their set of possible selves (Markus and Nurius, 1986). In a series of clinical case studies involving both individual and couples in psychotherapy, Singer found self-defining memories to be linked to critical relationship themes which were expressed in both clients' intimate relationships and in the transference dynamics of the therapy (Singer and Singer, 1992, 1994; Singer and Salovey, 1996; Singer, 2001; Singer and Blagov, 2004).

In addition to their linkage to goals, SDMs also can play directive and mood regulatory functions for the self (Pillemer, 1998, 2003; Bluck, 2003). For example, SDMs have been found to play a role in providing life lessons or integrative meanings that help individuals in optimal adjustment and personal growth. This is what Bluck (2003) termed the directive function of autobiographical memories. Blagov and Singer (2004) demonstrated that individuals with larger numbers of SDMs that contained reflective themes or messages, as reliably coded by three raters (see Singer and Blagov (2000) for an SDM coding manual), displayed optimal levels of self-restraint and emotional expression, as measured by the Weinberger Adjustment Inventory Short Form (Weinberger, 1997, 1998). Thorne et al. (2004) found that, compared to other types of personal memories, individuals were more likely to rely on SDMs involving tension or goal conflict to provide insights and life lessons.

SDMs provide information that can guide and direct the individual in everyday life. One specific form of directive function is the regulation of mood. Josephson et al. (1996) found that nondepressed individuals enlisted positive memories to repair negative moods, while mildly depressed individuals were less likely to recruit positive memories after a negative mood had been induced. Similarly, Moffitt et al. (1994) found that depressed individuals were less likely to recall SDMs when asked to retrieve a positive memory, while they did not differ in memory specificity for negative memories. Williams (1996), though not specifically addressing SDMs, has argued that a lack of memory specificity in depressed and suicidal individuals reflects a cognitive deficit generalized from a learned defense against encoding and retrieving affectively threatening self-relevant experiences. In summary, the findings from a broad range of studies converge on the view that SDMs are central to goals and conflicts within the individual (see Singer, 2005); they provide important integrative lessons, insights, or directives for the working self (see especially Pillemer, 1998); and they may regulate mood in important ways.

## 2.46.6 Self-Images

Conway et al. (2004) describe what they termed the conceptual self. One important knowledge structure in the conceptual self are self-images. It is proposed that self-images are knowledge structures that summarize complex sets of interlinked autobiographical knowledge and episodic memories that cumulatively support a particular view or version of the self. (Note that self-images can be permanent stable representations or more transitory, fleeting mental representations.) Conway (2005) proposes that these summary representations may often be experienced as images and hence the term self-images. A question of some interest here is how self-images are related to selective sets of memories. Rathbone et al. (2006; described in Conway, 2005) studied this by having a group of middle-aged participants complete a short questionnaire in which they completed six 'I am…' statements (Kuhn and McPartland, 1954). An 'I am…' could be anything, for example, I am bad, I am sociable, I am a banker, I am a mother, etc. Later each person recalled specific autobiographical memories to each of their 'I am…' statements. The dates of the memories, expressed in age at encoding, and the dates of the emergence of the 'I am…' statement were then compared; **Figure 5** shows the distribution of age at encoding of the memories relative to age of emergence of the 'I ams…'. **Figure 5** strikingly shows that age at encoding clusters around the date of emergence of the 'I ams…,' strongly

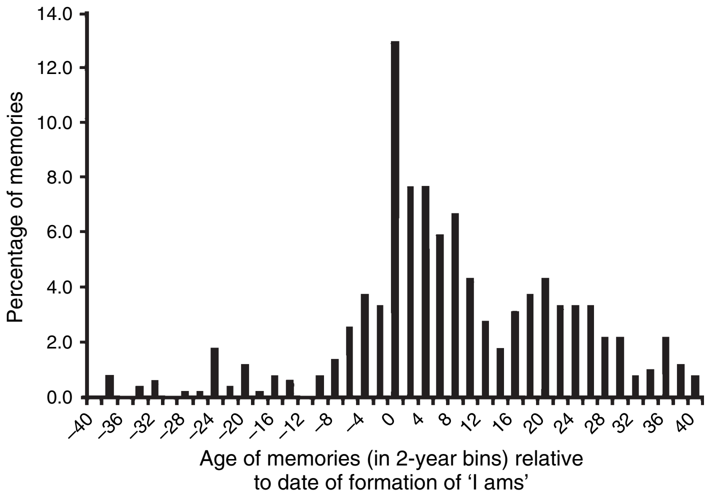


**Figure 5** Distribution of memories recalled to "I ams…" (Rathbone et al., 2006).

suggesting that 'I ams…' or self-images are grounded in sets of memories of formative experiences.

Further work found that the 'I ams…' could be categorized into two broad classes: roles and traits, e.g., I am a student versus I am charming. However, both types of 'I ams…,' role and trait, gave rise to the same distribution as that shown for 'I ams…' overall in **Figure 5**. Both role and trait 'I ams…' seem then to be marked in memory by highly accessible specific memories that come first to mind when the 'I am…' is processed. This may reflect the grounding of these aspects of the conceptual self, self-images, in subsets of memories and knowledge that define and provide the content for that self-image. This differentiation of the self, supported by the organization of autobiographical memory into self-images, might be particularly important in the development of the self – a point we return to after considering the distribution of memories over the life span and the significance of this for the self.

## 2.46.7 The Life Span Distribution of Autobiographical Memories

Important periods of development of the self are reflected in the life span retrieval curve which is observed when older adults (about 35 years and older) recall autobiographical memories in free recall or in a variety of cued recall conditions (Franklin and Holding, 1977; Fitzgerald and Lawrence, 1984; Rubin et al., 1986, 1998). Memories are plotted in terms of age at encoding of the remembered experiences, and the resulting life span retrieval curve typically takes a form similar to that shown in **Figure 6** (this is an

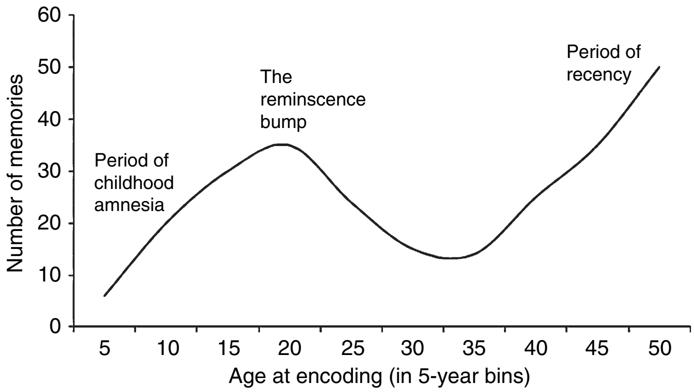


**Figure 6** Idealized representation of the life span retrieval curve. From Conway MA (2005) Memory and the self. *J. Mem. Lang.* 53(4): 594–628.

idealized representation derived from many studies and not based on specific data).

As **Figure 6** shows, the life span retrieval curve consists of three components: the period of childhood amnesia (from birth to approximately 5 years of age), the period of the reminiscence bump (from 10 to 30 years), and the period of recency (from the present declining back to the period of the reminiscence bump). The pattern of the life span retrieval curve is extremely robust and has been observed in many studies – to such an extent that it led Rubin to conclude that it was one of the most reliable phenomena of contemporary memory research (Conway and Rubin, 1993). This reliability is remarkably striking. In a recent study, Conway et al. (2005) sampled groups from five different countries: the United States, the United Kingdom, Bangladesh, Japan, and China. **Figure 7** shows the life span retrieval curves for each of these countries. (Note that participants were instructed not to recall events from the previous year to eliminate the recency portion of the curve.)

It can be seen from **Figure 7** that there were highly similar periods of childhood amnesia and reminiscence bump across countries. This further demonstrates the robustness of the life span retrieval curve and perhaps its universality. If the data for the five countries are collapsed together and an overall life span retrieval curve plotted, then the remarkably consistent distribution shown in the idealized curve of **Figure 6** is observed.

There are many theoretical explanations of the period of childhood amnesia (see Pillemer and White 1989; Wang, 2003, for reviews), but most flounder on the fact that children below the age of 5 years have a wide range of specific and detailed autosbiographical memories (Fivush et al., 1996; Bauer, 1997). Explanations that postulate childhood amnesia to be related to general developmental changes in intellect, language, emotion, etc., fail simply because apparently normal autobiographical memories were in fact accessible when the individual was in the period of childhood amnesia. It seems unlikely that an increase in general functioning would make unavailable previously accessible memories. From the SMS perspective, this period is seen as reflecting changes in the working self goal hierarchy, the idea being that the goals of the infant and young child, through which experience is encoded into memory, are so different, so disjunct, from those of the adult that the adult working self is unable to access those memories (see also Howe and Courage, 1997, for a particularly interesting account of childhood amnesia in terms of development of the self). Other accounts emphasize mother/child interactions, the role of language development, and emergence of narrative abilities (Fivush and Nelson, 2004).

Socialization and culture must play some role in the development of memory, although it seems that the infant/child capacity to actually have episodic memories may predate these developments (Rovee-Collier, 1997). If this is the case, then presumably the effects of socialization, culture, and language are largely on the organization of memory and perhaps on memory content as well, rather than on the processes that mediate the actual formation of episodic memories. For instance, the finding of Conway et al. (2005) that U.S. participants retrieved earlier earliest memories than all other groups might relate to the

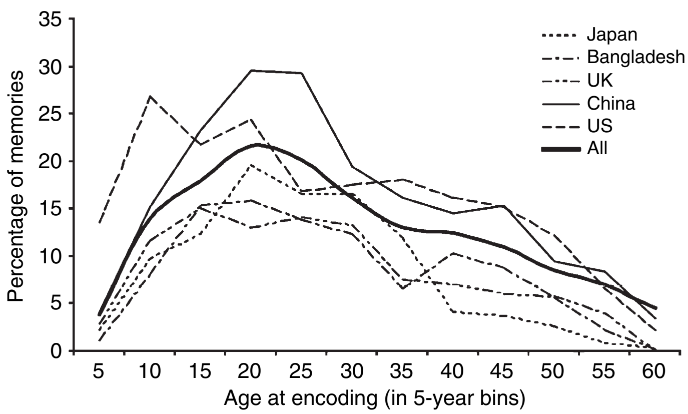


**Figure 7** Life span retrieval curves from five countries. From Conway MA (2005) Memory and the self. *J. Mem. Lang.* 53(4): 594–628.

observation that U.S. mothers undertake more memory talk with their children than mothers from other countries. Moreover, Wang and her colleagues (e.g. Wang, 2001) have found powerful cross-cultural differences in the focus and content of memories. Childhood memories from people in cultures with interdependent self-focus (Markus and Kitayama, 1991) such as China tend to be less oriented to the individual, less emotional, and more socially oriented than the childhood memories of people from cultures with independent self-focus, for example, Northern European or North American cultures (see Wang, 2001). Thus, socialization experiences and the self-focus that predominates in a culture may influence the accessibility of earliest memories and their content.

The second component of the life span retrieval curve is the period when rememberers were aged 10 to 30 years, known as the reminiscence bump (Rubin et al., 1986). The reminiscence bump is distinguished by an increase in recall of memories relative to the periods that precede and follow it. The reminiscence bump is present not just in the recall of specific autobiographical memories but also emerges in a range of different types of autobiographical knowledge. For example, the reminiscence bump has been observed in the recall of films (Sehulster, 1996), music (cf. Rubin et al., 1998), books (Larsen, 1998), and public events (Schuman et al., 1997; Holmes and Conway, 1999). Memories recalled from the period of the reminiscence bump are more accurate (Rubin et al., 1998), are judged more important than memories from other time periods, and are rated as highly likely to be included in one's autobiography (Fitzgerald, 1988; Fromholt and Larsen, 1991, 1992; Fitzgerald, 1996; Rubin and Schulkind, 1997). The reminiscence bump is only observed in people over the age of about 35 years and some recent findings suggest that it might only be present, or is much more prominent, in memories of positive experiences (Rubin and Bernsten, 2003).

Many of the more obvious explanations of the reminiscence bump have been rejected, e.g., that the memories are of first-time experiences and that is why they are memorable, as in fact it has been found that less than 20% are typically of first-time experiences (Fitzgerald, 1988). Rubin et al. (1998) reviewed a series of potential explanations and argued in favor of an explanation in terms of novelty. According to this view, the period when people are aged 10–30 years, and especially 15–25 years, is distinguished by novel experiences, occurring during a period of rapid change that gives way to a period of stability. It is assumed that memories from the period of rapid change are more distinct than those from the period of stability and this is why they are comparatively more frequently accessed. By this account, a period of rapid change taking place at some other point in the life cycle should also lead to raised accessibility of memories from that period relative to more stable periods, and there is some evidence that this is the case (Conway and Haque, 1999). However, periods of (goal) change and experiences of novelty always involve the self and a related but alternative explanation is that the high accessibility of memories from this period (and other periods as well) may be related to their enduring relation to the self (Conway and Pleydell-Pearce, 2000). Possibly, many memories from the period of the reminiscence bump are memories of self-defining experiences (see Fitzgerald, 1988) and have a powerful effect in cohering the working self into a particular form. The novelty of reminiscence bump experiences lies in their newness and uniqueness for the self and they may play a crucial role in the final formation of a stable self system and identity formation during late adolescence and early adulthood. The raised accessibility of these memories might then serve processes relating to the coherence of self through time.

Thus, the period of the reminiscence bump might be a period in which a sole 'I am...,' or self-image, develops into multiple 'I ams...,' e.g., I am a son, I am a student, I am a boyfriend, etc. Also, at this point multiple 'I will becomes...' may be formed, supported by the differentiation of 'I ams...' and the final emergence of a complete working self goal hierarchy and conceptual self grounded in autobiographical knowledge and memories (the SMS). Finally it might be noted that older patients with schizophrenia have been found to show an early and disorganized reminiscence bump, with an impairment of conscious recollection associated with memories highly relevant to personal identity (Cuevo-Lombard et al., 2007). This suggests that a developmental failure present in schizophrenia is the consolidation of personal identity in late adolescence/early adulthood. Possibly, one of the features of the abnormal SMS associated with this is a failure or weakening of the grounding of conceptual autobiographical knowledge in episodic memories of formative experiences, further demonstrating the importance of an integrated self with self-images strongly embedded in sets of defining episodic memories.

## 2.46.8 Closing Section: Why Do We Have Autobiographical Memory?

In many respects this may seem a pointless or rhetorical question; after all, if we did not have autobiographical memory there would be little in the way of individuality, personality, culture, society, literature, etc. Much that differentiates humanity from other species would be absent (see Tulving, 1983). At the level of the individual, disruption to or loss of autobiographical memory leads to people who typically cannot function in society. For example, clinically depressed patients often have severely impaired autobiographical memories in which they can no longer generate specific memories, their memories lack detail, they are overly general (Williams, 1996). Such patients cannot operate in the social world and, moreover, have unspecific futures in which they cannot visualize specific plans and goals (Williams et al., 2007a). Similarly, with amnesic patients whose memory disorders arise from organic brain damage, having multiple self-images in a specific future in which goals and plans originating from memories of the past are realized is no longer possible. Thus, one good reason to have an intact and functioning autobiographical memory is that it allows the individual to have a future in which a continuous self operates.

But what does this mean? The future is, of course, a time where new experiences, some anticipated, will take place. But we cannot know we have arrived at the future without a memory – that is, without knowledge of a past. The concept of future makes no sense, conceptually or psychologically, without a past. One way to think about this is to conceive of the future as a place where new goal processing will take place and the past as some sort of record of previous episodes of goal processing. To achieve future goals it is essential to have a record of how one has progressed with the same or related goals in the past. Consider very recent goals. In order to know that one locked the car after parking it this morning, we simply remember that episode. The events of the current day can typically be recalled (on that day) at length and in highly specific detail. Thus, checking on progress with goals, locking the car, making a call, mailing a paper, etc., can be verified. However, within a few days, access to these sorts of detailed memories is lost. No doubt this is useful as retaining a highly detailed record of every action would lead to an overloaded and unworkable memory. Nonetheless, keeping a detailed record in the short term is highly adaptive and prevents the repetition of actions and the adoption of courses of actions that have a high probability of failing.

Conway (2005) argues that episodic memory is the memory system that keeps a record of very recent goal-related activities. It is a system that has evolved highly specific memory representations that facilitate the type of short-term goal processing that can keep goals focused and environmentally relevant. It is suggested that this is a species-wide adaptation and, consequently, episodic memory is common to many species. As such it is probably a phylogenetically older memory system and may be represented in neural networks located toward the middle and posterior of the brain (a temporal-occipital network; see Conway, 2005). In contrast, humans have developed conceptual knowledge that forms complex knowledge structures that endure over long periods of time, even over a lifetime. This, it is suggested, is a more recent evolutionary development and is mediated by neural networks toward the front of the brain: fronto-temporal regions. The conceptual memory system supports long-term goal processing, for example, relationships, work projects, etc. Episodic memories that are retained become attached to conceptual knowledge and provide highly specific instances of goal processing related to the more general or generic goals of the conceptual self and self-images. Autobiographical memory then allows us to have both short- and long-term goals and to integrate these in coherent ways that facilitate goal processing in the future.

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## References

Barsalou LW (1988) The content and organization of autobiographical memories. In: Neisser U and Winograd E (eds.) *Remembering Reconsidered: Ecological and Traditional Approaches to the Study of Memory*, pp. 193–243. Cambridge: Cambridge University Press.

Bartlett FC (1932) *Remembering: A Study in Experimental and Social Psychology*. Cambridge: Cambridge University Press.

Bauer P (1997) Development of memory in early childhood. In: Cowan N (ed.) *The Development of Memory in Childhood*, pp. 83–112. Sussex: Psychology Press.
Beike DR and Landoll SL (2000) Striving for a consistent life story: Cognitive reactions to autobiographical memories. *Soc. Cogn.* 18: 292–318.
Blagov PS and Singer JA (2004) Four dimensions of self-defining memories (specificity, meaning, content, and affect) and their relationships to self-restraint, distress, and repressive defensiveness. *J. Pers.* 72: 481–511.
Bluck S (2003) Autobiographical memory: Exploring its functions in everyday life. *Memory* 11: 113–123.
Bluck S and Habermas T (2000) The life story schema. *Motiv. Emot.* 24: 121–147.
Bluck S and Habermas T (2001) Extending the study of autobiographical memory: Thinking back about life across the life span. *Rev. Gen. Psychol.* 5: 135–147.
Brewer WF (1988) Memory for randomly sampled autobiographical events. In: Neisser U and Winograd E (eds.) *Remembering Reconsidered: Ecological and Traditional Approaches to the Study of Memory*, pp. 21–90. New York: Cambridge University Press.
Brown NR and Schopflocher D (1998) Event clusters: An organization of personal events in autobiographical memory. *Psychol. Sci.* 9: 470–475.
Brown R and Kulik J (1977) Flashbulb memories. *Cognition* 5: 73–99.
Burt CDB, Kemp S, and Conway MA (2003) Themes, events, and episodes in autobiographical memory. *Mem. Cogn.* 31: 317–325.
Cantor N and Kihlstrom JF (1985) Social intelligence: The cognitive basis of personality. In: Shaver P (ed.) *Self, Situations, and Social Behavior. Review of Personality and Social Psychology*, pp. 15–34. Beverly Hills: Sage.
Cohen G (1989) *Memory in the Real World,* 1st edn. Hillsdale, NJ: Erlbaum.
Conway MA (1990) *Autobiographical Memory: An Introduction*. Buckingham: Open University Press.
Conway MA (1993) The structure of memory. In Conway MA and Morris PE (eds.) *International Library of Critical Writings in Psychology, Vol. 2: Memory Structure,* pp. 21–27. Cheltenham: Edward Elgar Publishing.
Conway MA (1996) Autobiographical memories and autobiographical knowledge. In: Rubin DC (ed.) *Remembering Our Past: Studies in Autobiographical Memory*, pp. 67–93. Cambridge: Cambridge University Press.
Conway MA (2001) Sensory perceptual episodic memory and its context: Autobiographical memory. *Philos. Trans. R. Soc. Lond.* 356: 1297–1306.
Conway MA (2004) Autobiographical memory and the self. In: Byrne JH, Eichenbaum H, Roediger H III, and Thompson RF (eds.) *Learning and Memory,* 2nd edn. Farmingham Hills, MI: Macmillan Reference.
Conway MA (2005) Memory and the self. *J. Mem. Lang.* 53(4): 594–628.
Conway MA and Bekerian DA (1987) Organization in autobiographical memory. *Mem. Cogn.* 15 119–132.
Conway MA and Fthenaki A (2000) Disruption and loss of autobiographical memory. In: Cermak LS (ed.) *Handbook of Neuropsychology: Memory and Its Disorders,* 2nd edn., pp. 281–312. Amsterdam: Elsevier.
Conway MA and Haque S (1999) Overshadowing the reminiscence bump: Memories of a struggle for independence. *J. Adult Dev.* 6: 35–44.
Conway MA and Pleydell-Pearce CW (2000) The construction of autobiographical memories in the self memory system. *Psychol. Rev.* 107: 261–288.
Conway MA and Rubin DC (1993) The structure of autobiographical memory. In: Collins AE, Gathercole SE, Conway MA, and Morris PEM (eds.) *Theories of Memory*, pp. 103–137. Hove, Sussex: Lawrence Erlbaum.
Conway MA, Singer JA, and Tagini A (2004) The self and autobiographical memory: Correspondence and coherence. *Soc. Cogn.* 22: 495–537.
Conway MA, Wang Q, Hanyu K, and Haque S (2005) A cross-cultural investigation of autobiographical memory: On the universality and cultural variation of the reminiscence bump. *J. Cross-Cultur. Psychol.* 36: 739–749.
Crovitz HF and Schiffman H (1974) Frequency of episodic memories as a function of their age. *Bull. Psychon. Soc.* 4: 517–518.
Cuevo-Lombard C, Jovenin N, Hedelin G, Rizzo-Peter L, Conway MA, and Danion J-M (2007) Autobiographical memory of adolescence and early adulthood events: An investigation in schizophrenia. *J. Int. Neuropsychol. Soc.* 13: 335–343.
Demorest AP and Alexander IE (1992) Affective scripts as organizers of personal experience. *J. Pers.* 60: 645–663.
De St. Aubin E and McAdams DP (1995) The relations of generative concern and generative action to personality traits, satisfaction/happiness with life, and ego development. *J. Adult Dev.* 2: 99–112.
Ebbinghaus H (1885/1964) *Memory: A Contribution to Experimental Psychology,* Ruger HA and Bussenius CE (trans.). New York: Dover Publications.
Ehlers A and Clark DM (2000) A cognitive model of posttraumatic stress disorder. *Behav. Res. Ther.* 38: 319–345.
Fitzgerald JM (1988) Vivid memories and the reminiscence phenomenon: The role of a self narrative. *Hum. Dev.* 31: 261–273.
Fitzgerald JM (1996) Intersecting, meanings of reminiscence in adult development and aging. In: Rubin DC (ed.) *Remembering Our Past: Studies in Autobiographical Memory*, pp. 360–383. Cambridge: Cambridge University Press.
Fitzgerald JM and Lawrence R (1984) Autobiographical memory across the lifespan. *J. Gerontol.* 39: 692–698.
Fivush R and Nelson K (2004) Culture and language in the emergence of autobiographical memory. *Psychol. Sci.* 15: 573–577.
Fivush R, Hayden C, and Reese E (1996) Remembering, recounting, and reminiscing: The development of memory in a social context. In: Rubin D (ed.) *Remembering Our Past: Studies in Autobiographical Memory*, pp. 341–359. Cambridge: Cambridge University Press.
Franklin HC and Holding DH (1977) Personal memories at different ages. *Q. J. Exp. Psychol.* 29: 527–532.
Fromholt P and Larsen SF (1991) Autobiographical memory in normal aging and primary degenerative dementia (dementia of the Alzheimer type). *J. Gerontol. Psychol. Sci.* 46: 85–91.
Fromholt P and Larsen SF (1992) Autobiographical memory and life-history narratives in aging and dementia (Alzheimer type). In: Conway MA, Rubin DC, Spinnler H, and Wagenaar WA (eds.) *Theoretical Perspectives on Autobiographical Memory*, pp. 413–426. Dordrecht: Kluwer.
Galton F (1883) *Inquiries into Human Faculty and Its Development*, 1st edn. London: Macmillan and Co.
Gardiner JM and Richardson-Klavehn A (2000) Remembering and knowing. In: Tulving E and Craik FIM (eds.) *Handbook of Memory*, pp. 229–244. Oxford: Oxford University Press.
Henri V and Henri C (1896) Enquête sur les premiers souvenirs de l'enfance. *Année Psychol.* 3: 184–198.
Henri V and Henri C (1898) Earliest recollections. *Pop. Sci. Month.* 53: 108–115.
Holmes A and Conway MA (1999) Generation identity and the reminiscence bump: Memory for public and private events. *J. Adult Dev.* 6: 21–34.

Howe ML and Courage ML (1997) The emergence and early development of autobiographical memory. *Psychol. Rev.* 104: 499–523.
Jardine KF (1999) Transitions of women counsellors-in-training: Self-defining memories, narratives, and possible selves. *Diss. Abst. Int. A Hum. Soc. Sci.* 59(11-A): 4068.
Josephson B, Singer JA, and Salovey P (1996) Mood regulation and memory: Repairing sad moods with happy memories. *Cogn. Emo.* 10: 437–444.
Kuhn MH and McPartland TS (1954) An empirical investigation of self attitudes. *Am. Sociol. Rev.* 19: 68–76.
Lancaster JS and Barsalou LW (1997) Multiple organisations of events in memory. *Memory* 5: 569–599.
Larsen SF (1998) What is it like to remember? On phenomenal qualities of memory. In: Thompson CP (ed.) *Autobiographical Memory: Theoretical and Applied Perspectives*, pp. 163–190. Mahwah, NJ: Lawrence Erlbaum.
Markus HR and Kitayama S (1991) Culture and the self: Implications for cognition, emotion, and motivation. *Psychol. Rev.* 98: 224–253.
Markus H and Nurius P (1986) Possible selves. *Am. Psychol.* 41: 954–969.
McAdams DP (1982) Experiences of intimacy and power: Relationships between social motives and autobiographical memory. *J. Pers. Soc. Psychol.* 42: 292–302.
McAdams DP, Hoffman BJ, Mansfield ED, and Day R (1996) Themes of agency and communion in significant autobiographical scenes. *J. Pers.* 64: 229–378.
McAdams DP, Reynolds J, Lewis M, Patten AH, and Bowman PJ (2001) When bad things turn good and good things turn bad: Sequences of redemption and contamination in life narrative and their relation to psychosocial adaptation in midlife adults and in students. *Pers. Soc. Psychol. Bull.* 27: 474–485.
Moffitt KH and Singer JA (1994) Continuity in the life story: Self-defining memories, affect, and approach/avoidance personal strivings. *J. Pers.* 62: 21–43.
Moffitt KH, Singer JA, Nelligan DW, Carlson MA, and Vyse SA (1994) Depression and memory narrative type. *J. Abnorm. Psychol.* 103: 581–583.
Moulin CJA, Conway MA, Thompson RG, James N, and Jones RW (2005) Disordered memory awareness: Recollective confabulation in two cases of persistent déjà vécu. *Neuropsychologia* 43: 1362–1378.
Neisser U (1978) Memory: What are the important questions? In: Gruneberg MM, Morris PE, and Sykes RN (eds.) *Practical Aspects of Memory*. London: Academic Press.
Neisser U (ed.) (1982) *Memory Observed: Remembering in Natural Contexts*, San Francisco: Freeman.
Pillemer DB (1998) *Momentous Events, Vivid Memories*. Cambridge, MA: Harvard University Press.
Pillemer DB (2003) Directive functions of autobiographical memory: The guiding power of the specific episode. *Memory* 11: 193–202.
Pillemer DB and White SH (1989) Childhood events recalled by children and adults. *Adv. Child Dev. Behav.* 21: 297–340.
Quinn DK (1990) Freedom on wheels. *The Christian Science Monitor.* April 19, p. 17. Cited in Robinson JA (1992) First experience memories: Contexts and function in personal histories. In: Conway MA, Rubin DC, Spinnler H, and Wagenaar W (eds.) *Theoretical Perspectives on Autobiographical Memory*, pp. 223–239. Dordrecht, The Netherlands: Kluwer.
Rapaport D (1950/1971) *Emotions and Memory*. New York: International Universities Press.
Rathbone CJ, Moulin CJA, and Conway MA (2006) Autobiographical memory and identity: Self-centred memories. Presented at the Fourth International Conference on Memory (ICOM-4), Sydney, Australia, July.
Ribot T (1882) *Diseases of Memory: An Essay in the Positive Psychology,* Smith WH (trans.). New York: D. Appleton.
Robinson JA (1976) Sampling autobiographical memory. *Cogn. Psychol.* 8: 578–595.
Robinson JA (1992) First experience memories: Contexts and function in personal histories. In: Conway MA, Rubin DC, Spinnler H, and Wagenaar W (eds.) *Theoretical Perspectives on Autobiographical Memory*, pp. 223–239. Dordrecht, The Netherlands: Kluwer.
Rovee-Collier C (1997) Dissociations in infant memory: Rethinking the development of implicit and explicit memory. *Psychol. Rev.* 104: 467–498.
Rubin DC and Berntsen D (2003) Life scripts help to maintain autobiographical memories of highly positive, but not highly negative, events. *Mem. Cogn.* 31: 1–14.
Rubin DC and Schulkind MD (1997) The distribution of autobiographical memories across the lifespan. *Mem. Cogn.* 25: 859–866.
Rubin DC, Wetzler SE, and Nebes RD (1986) Autobiographical memory across the life span. In: Rubin DC (ed.) *Autobiographical Memory*. Cambridge: Cambridge University Press.
Rubin DC, Rahhal TA, and Poon LW (1998) Things learned in early adulthood are remembered best. *Mem. Cogn.* 26: 3–19.
Schuman H, Belli RF, and Bischoping K (1997) The generational basis of historical knowledge. In: Jodelet D, Pennebaker J, and Paez D (eds.), *Political Events and Collective Memories*, pp. 47–78. London: Routledge.
Sehulster JR (1996) In my era: Evidence for the perception of a special period in the past. *Memory* 4: 145–158.
Singer JA (1990) Affective responses to autobiographical memories and their relationship to long-term goals. *J. Pers.* 58: 535–563.
Singer JA (2001) Living in the amber cloud: A life story analysis of a heroin addict. In: McAdams DP, Josselson R, and Lieblich A (eds.) *Turns in the Road: Narrative Studies of Lives in Transition*, pp. 253–277. Washington, DC: American Psychological Association.
Singer JA (2005) *Memories That Matter: Using Self-Defining Memories to Understand and Change Your Life*. Oakland: New Harbinger.
Singer JA and Blagov PS (2000) Classification system and scoring manual for self-defining autobiographical memories. Paper presented at the meeting of the Society for Applied Research on Memory and Cognition, Miami Beach, FL, June.
Singer JA and Blagov PS (2004) Self-defining memories, narrative identity, and psychotherapy: A conceptual model, empirical investigation, and case report. In: Angus LE and McLeod J (eds.) *Handbook of Narrative and Psychotherapy: Practice, Theory and Research*, pp. 229–246. Thousand Oaks CA: Sage.
Singer JA and Moffitt KH (1991/1992) An experimental investigation of specificity and generality in memory narratives. *Imagin. Cogn. Pers.* 11: 233–257.
Singer JA and Salovey AP (1993) *The Remembered Self*. New York: The Free Press.
Singer JA and Salovey AP (1996) Motivated memory: Self-defining memories, goals, and affect regulation. In: Martin L and Tesser A (eds.) *Striving and Feeling: Interactions Among Goals, Affect, and Self-Regulation*, pp. 229–250. Hillsdale, NJ: Erlbaum.
Singer JA and Singer JL (1992) Transference in psychotherapy and daily life: Implications of current memory and social cognition research. In: Barron JW and Eagle MN (eds.) *Interface of Psychoanalysis and Psychology*, pp. 516–538. Washington, DC: American Psychological Association.
Singer JA and Singer JL (1994) Social-cognitive and narrative perspectives on transference. In: Masling JM and Bornstein

RF (eds.) *Empirical Perspectives on Object Relations Theory. Empirical Studies of Psychoanalytic Theories,* vol. 5, pp. 157–193. Washington, DC: American Psychological Association.

Singer JA, King LA, Green MC, and Barr SC (2002) Personal identity and civic responsibility: ''Rising to the occasion'' narratives and generativity in community action interns. *J. Soc. Issues* 58: 535–556.

Smith ME (1952) Childhood memories compared with those of adult life. *J. Genet. Psychol.* 80: 151–182.

Thorne A, Cutting L, and Skaw D (1998) Young adults' relationship memories and the life story: Examples or essential landmarks. *Narr. Inq.* 8: 237–268.

Thorne A, McLean KC, and Lawrence AM (2004) When remembering is not enough: Reflecting on self-defining memories in late adolescence. *J. Pers.* 72: 513–542.

Tulving E (1983) *Elements of Episodic Memory*. Oxford: Oxford University Press.

Tulving E (1985) Memory and consciousness. *Can. Psychol.* 26: 1–12.

Wang Q (2001) Cultural effects on adults' earliest childhood recollection and self-description: Implications for the relation between memory and the self. *J. Pers. Soc. Psychol.* 81: 220–233.

Wang Q (2003) Infantile amnesia reconsidered: A cross-cultural analysis. *Memory* 11: 65–80.

Weinberger DA (1997) Distress and self-restraint as measures of adjustment across the life span: Confirmatory factor analyses in clinical and non-clinical samples. *Psychol. Assess.* 9: 132–135.

Weinberger DA (1998) Defenses, personality structure, and development: Integrating psychodynamic theory into a typological approach to personality. *J. Pers.* 66: 1061–1080.

Williams JMG, Barnhofer T, Crane C, et al. (2007a) Autobiographical memory specificity and emotional disorder. *Psychol. Bull.* 133(1): 122–148.

Williams HL, Conway MA, and Baddeley AD (2007b) The boundaries of episodic memories. In: Shipley TF and Zacks JM (eds.) *Understanding Events: How Humans See, Represent, and Act on Events*. New York: Oxford University Press.

Williams JMG (1996) Depression and the specificity of autobiographical memory. In: Rubin DC (ed.) *Remembering Our Past: Studies in Autobiographical Memory*, pp. 244–267. Cambridge: Cambridge University Press.

Zacks JM, Speer NK, Swallow KM, Braver TS, and Reynolds JR (2007) Event perception: A mind/brain perspective. *Psychol. Bull.* 133: 273–293.

# 2.47 Social Memory Processes

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In 1932, Bartlett published a classic book on memory in which he rebelled against the prevailing Ebbinghaus tradition that focused on people's ability to reproduce lists of words or nonsense syllables. Bartlett argued for the importance of studying memory of more complex and meaningful material. He also opposed the idea, still common today (e.g., Kandel, 2006), that remembering is analogous to mental time travel. This analogy implies that people can go back in time and recapture their original experiences. The invalidity of this assumption is perhaps evident to most people with memory for emotionally tinged events. The negative emotions associated with adverse events fade markedly with time. Similar fading of emotional intensity occurs for positive events, but at a much slower rate (Walker et al., 2003).

Bartlett emphasized that memory of more complex information often involves active reconstruction, in addition to the reactivation of lasting traces in nerve cells in the brain. He suggested that remembering is guided by present knowledge and goals, with the result being that a reconstruction can differ from the original experience. Bartlett also noted that remembering can be a collaborative as well as an individual activity, and that people develop particular memory skills in response to the demands of their social, cultural, and physical environments. Bartlett highlighted the importance of social factors by entitling his book *Remembering: A Study in Experimental and Social Psychology*.

Today, most psychologists studying memory focus on the cognitive and neurological factors underlying individual recall. It is social psychologists who have picked up Bartlett's themes regarding the social aspects of remembering. Social psychologists study topics such as self-conceptions, attitude formation, relationships, conformity, and conflict. They do not typically study memory *per se*. Nevertheless, memory, and especially autobiographical memory, plays an active role in many phenomena of interest to social psychologists. Autobiographical memories and self-conceptions are closely related (James, 1950; Singer and Salovey, 1993; Pillemer, 1998; Conway and Pleydell-Pearce, 2000; McAdams, 2001; Bluck, 2003; Ross and Wilson, 2003). People can use their memories to assess their beliefs, traits, self-worth, and social acceptance, as well as to guide their actions and decisions.

According to Bartlett (1932) and Neisser (1967), people often remember only a few elements of an episode; they then use their current knowledge and beliefs to fill in gaps and resolve ambiguities in their memories. Rememberers reconstruct what should (or must) have happened and confuse their reconstruction with recollection: They suppose that what should have happened did happen (Bartlett, 1932; Mead, 1964; Neisser, 1967; Ross, 1989). Although people are better than Bartlett proposed at distinguishing their suppositions from their recall (Roediger et al., 2001), his analysis provides a useful conceptual tool for examining when and how the present affects recollections.

The reconstructive aspect of memory has perhaps been overemphasized relative to another important characteristic of memory: its selectivity. In remembering and reconstructing the past, people focus on some episodes and not others (e.g., memory of a particular wedding), and on some aspects of episodes rather than others (Rogers et al., 1977; Bellezza, 1984; Symons and Johnson, 1997). People's current goals and motives can influence both the selection of past episodes and their reconstruction. Past experiences are often sufficiently numerous, contradictory, and ambiguous that people can use selection, reconstruction, or both to remember what they need or prefer to recall. A man motivated to recall happy times in his marriage will typically remember at least some pleasant memories involving his partner. When motivated to recall unhappy times, the same man would probably remember some unpleasant memories. As we shall see, however, there are constraints on memory: Remembering is not just wish fulfillment.

In the present chapter, we discuss research on the effects of present knowledge, goals, and motivation on individual recall. Because people often remember as pairs or groups in real life, we also review research on two important forms of joint remembering. People collaborate to recall dates, names, and past events. We examine research on the effects of collaboration on accuracy of recall. Also, people often exchange memories with other individuals. Indeed, much of people's knowledge of events comes from others, including friends, family, teachers, and the media. We examine how memories change as they are transmitted from one person to another, as well as how these changes affect people's beliefs and attitudes.

## 2.47.1 The Effects of the Present on Recall

In everyday life, the hindsight bias, or the I-knew-it-all-along effect, is perhaps the most widely recognized example of the influence of the present on recall. According to a popular cliché, hindsight is 20-20. In research on the hindsight bias, psychologists compare hindsight judgments made with knowledge of an outcome (e.g., the winner of an obscure military battle) to foresight judgments made without such knowledge. Participants in the hindsight condition typically regard the actual outcome as more likely than do those in the foresight condition (Fischhoff and Beyth, 1975; Slovic and Fischhoff, 1977; Hoffrage et al., 2000). For example, Fischhoff and Beyth (1975) asked university students to predict the likelihood of various events before President Nixon's visits to Beijing and Moscow. After Nixon's trips, these students remembered assigning higher probabilities than they originally did to events that actually occurred. Presumably participants had a difficult time recalling the exact probabilities that they had assigned. In reconstructing their predictions, they used their present knowledge to estimate their prior probabilities (Hoffrage et al., 2000).

The hindsight bias has potentially important implications for people's assessments of behavior and individuals. When people evaluate past performances, they often know the outcomes (e.g., whether a medical diagnosis was valid or a military tactic was successful). The hindsight bias can inappropriately lead people to criticize individuals who fail and admire those who succeed. For example, physicians informed of both a patient's symptoms and autopsy results indicating the cause of death are surprised that other physicians could have made an incorrect diagnosis prior to the autopsy. Physicians told of the symptoms but not of the autopsy results are less certain of the diagnosis (Dawson et al., 1988). Alternatively, when events turn out well, successful people are sometimes credited with too much foresight. In *War and Peace*, Tolstoy accuses Russian historians of making this error in judgment (cited in Hoffrage et al., 2000). Historians wrote that the Russian army defeated Napoleon by tricking him into marching toward Moscow. However, the Russian victory was probably more attributable to luck than to foresight.

Researchers have extended investigations of hindsight by examining how people's current knowledge and beliefs influence their recall of their earlier attitudes, feelings, and behaviors. While recalling the past, people are often very aware of the present (Ross, 1989). For example, people know how they currently feel about a politician but may be less certain how they felt years earlier. Unless they have a compelling reason to think that they have changed, they often presume personal consistency, supposing that their earlier opinions resemble their current beliefs (Ross, 1989). The perception of consistency helps people to sustain a sense of personal identity: They are the same individuals that they were yesterday or last year (Erikson, 1968; Epstein, 1973; James, 1950). When people assume stability in the face of actual change, they exaggerate the similarity of the past to the present and evidence a consistency bias in recall.

## 2.47.2 A Consistency Bias in Recall

Much of the research demonstrating a consistency bias in recall examines people's memories of their earlier attitudes and feelings. Goethals and Reckman (1973) studied the effect of an experimentally induced change in attitudes on recall of earlier opinions. At an initial session, high school students completed a questionnaire indicating their attitudes on a variety of issues, including bussing students to achieve racial integration in the schools. At a second session 4–14 days later, the students received information that led them to change their views on bussing. They were then asked to recall their attitude responses on the initial questionnaire. They remembered responding more in harmony with their new position on bussing than they actually had. Following a change in attitudes, individuals tend to underestimate the degree to which they have altered their opinions.

Several researchers have examined this same phenomenon in the context of naturally occurring changes in evaluations. McFarland and Ross (1987) asked undergraduates to evaluate their dating partners at an initial session on a series of rating scales and then again months later. At the second session, participants also attempted to recall their earlier ratings. Presumably they could not easily remember precisely where they placed their x on the rating scales. As a result, they had to reconstruct their earlier evaluations. Apparently, participants based their reconstructions, in part, on their current impressions of their partners. Participants who became more favorable over time recalled more positive evaluations than they had provided originally; those who became less favorable recalled more negative evaluations.

Levine (1997) studied changes in feelings reported by supporters of Ross Perot, an independent candidate for the US presidency. Perot withdrew from the presidential race in July 1992 and then re-entered in October 1992. Levine polled Perot supporters immediately following his withdrawal and again following the election in November of the same year. After the election, supporters recalled the emotional reactions they had reported immediately following Perot's withdrawal 5 months earlier. Respondents' recall of their emotions following the withdrawal was consistent with their current political ideology. Those who continued to support Perot recalled feeling less anger and more hope than they had reported earlier.

Taking the consistency bias in recall one step further, Ross et al. (1981) examined how people's current attitudes affect their recall of their own past actions. To show a cause and effect relation between attitudes and behavioral recall, Ross et al. (1981) provided participants with communications that challenged their beliefs concerning certain health issues. For example, some participants learned of scientific evidence that frequent tooth brushing is potentially harmful to gums and tooth enamel. Shortly after reading the communication designed to change their attitudes toward tooth brushing, participants completed a questionnaire that assessed their frequency of engaging in various health-related behaviors in the previous 2 weeks. As anticipated, those who now believed that frequent tooth brushing was harmful recalled brushing less often than did participants not exposed to the anti–tooth brushing message.

If people recall behavioral histories that are consistent with their new beliefs, then the act of remembering past behavior could increase people's commitment to their new beliefs. On looking back, people 'discover' that they have behaved consistently with their new beliefs; this memory should support the validity of these beliefs. To test whether behavioral recall increases support for new attitudes, Ross et al. (1983) induced participants to change their attitudes. Some participants were then asked to recall past behavior relevant to the attitude domain in question. Their recall was not constrained. They were free to recall behaviors congruent or incongruent with their new opinions. Other participants did not engage in behavioral recall. Participants in the behavioral recall condition seemed to be more committed to their new attitudes. They were more likely to report intentions to act consistently with their new attitudes and more resistant to a message attacking their new attitudes than were participants who were not prompted to recall past behaviors. These findings suggest a reverberating circuit in which new attitudes affect behavioral recall, which in turn affects commitment to the new attitudes.

Studies of memory reconstruction point to the dangers of assuming the validity of people's recall. Recent research in cross-cultural psychology supports this concern. There is an extensive literature on cultural differences in the experience and determinants of emotion (e.g., Kitayama and Markus, 1994; Oishi, 2002). Much of this research on emotion is retrospective. For example, people are asked how frequently they felt various emotions in the last month (e.g., Eid and Diener, 2001). Researchers typically find that American and Canadians of European heritage recall experiencing many more positive (e.g., happy) than negative (e.g., sad) emotions in their everyday lives. In contrast, Americans and Canadians of East Asian heritage as well as respondents living in Japan report experiencing about the same number of positive and negative emotions (Markus and Kitayama, 1994; Oishi, 2002; Ross et al., 2002), and fewer positive emotions than European Americans and Canadians.

These research findings can be interpreted as indicating that Westerners are happier on a daily basis than are their East Asian counterparts. Alternatively, perhaps Western and East Asian individuals experience about the same number of pleasant and unpleasant episodes, but Westerners recall a greater number of their pleasant experiences. Such a recall bias in Western cultures could reflect a Western cultural schema that happiness is important and common, a cultural schema that is less evident among Eastern cultures (Oishi, 2002). Conceivably, Westerners and East Asians recruit memories that support their differing beliefs, with the result that Westerners recall more happy experiences.

Oishi (2002) compared retrospective accounts to daily diary and online reports of emotional experiences. European and Asian Americans did not differ in daily diary reports of the quality of their day, or in online reports of current positive and negative moods. Interestingly, cultural differences clearly emerged at the end of the week when participants were asked how good or bad the week was, or how often they had experienced positive and negative moods. European Americans retrospectively reported greater satisfaction with the week and a higher frequency of positive moods compared to Asian Americans.

Are East Asians less happy than their Western counterparts? The answer depends on whether the focus is on current or retrospective reports. As Oishi observed, "retrospective judgments seem to be as important as actual experiences in understanding subjective experiences of well-being . . . online and global reports capture different but equally important aspects of well-being" (Oishi, 2002: p. 1405).

Oishi's study is unlikely to be the final word on cultural differences in emotional experience. Researchers using other samples and procedures might find evidence of online differences. From the present perspective, the Oishi study is important for two reasons. First, it reminds us that recall should never be assumed to be an exact replica of earlier experience. Second, as Oishi notes, retrospective reports can be psychologically significant, even when they do not mirror online reports.

## 2.47.3 Motivated Recall

In presenting research on the effects of current beliefs on recall, we depicted the recall process as a rather dispassionate cognitive exercise. A new belief can be more than a recall cue, however; it can also motivate biased recall (Greenwald, 1980; Kunda, 1990). For example, in the tooth brushing study reported by Ross et al. (1981), people presumably preferred to believe that they had been behaving in a way that would not cause their teeth to rot or their gums to fall apart. Researchers examining the relation between motives and recall have studied both chronic motives and experimentally induced motives. The research evidence indicates that the content of autobiographical recall reflects people's persistent motives (e.g., McAdams, 1982; McAdams et al., 1996; Woike et al., 2003; Gramzow and Willard, 2006; Sahdra and Ross, 2007). For example, Sahdra and Ross (2007) examined how degree of identification with a religious group influenced people's recall of harms committed by members of that group. High identifiers (who are motivated to view their group favorably) were less likely than low identifiers to recall episodes in which members of their group acted violently toward members of a different religious group.

Other researchers have altered people's beliefs about the desirability of specific traits or behaviors and then assessed people's memories of their past actions. In studies conducted by Sanitioso and his associates, individuals were led to believe that a particular trait such as extraversion was or was not related to success in life. Participants who believed that extraversion is desirable were able to recall their own extraverted behaviors more quickly and easily than were participants who supposed that introversion is preferable (Sanitioso et al., 1990; Sanitioso and Niedenthal, 2006).

Murray and Holmes (1993) asked undergraduates in dating relationships to report the amount of conflict they had with their partner while deciding on joint activities. Participants in the experimental condition then read a bogus psychological article that argued that the development of intimacy in a relationship depended on people's willingness to express disagreement. Thus, experimental participants who had reported that they and their partner experienced little conflict now learned, much to their surprise, that low conflict was actually bad for a relationship. A control condition contained participants who had also reported low conflict with their partners, but who did not read the bogus article.

How did experimental participants deal with their new understanding that conflict was desirable? Many altered their views of their partner's past behaviors. When asked to assess their relationships on a number of dimensions, experimental participants were more likely than controls to endorse items such as "My partner clearly expresses his/her needs even when he/she knows that these needs conflict with my needs." In short, they discovered evidence that their relationship was appropriately conflict-ridden.

Baumeister and his colleagues (Baumeister et al., 1990, 1993; Stillwell and Baumeister, 1997) have studied how people who anger someone else (perpetrators) remember a dispute compared to individuals who are provoked (victims). Generally, perpetrators regard their behavior as less harmful and more justifiable than victims do. Along the same lines, young children recall disputes with their siblings in a manner that tends to absolve them of blame. They remember more harmful actions by their siblings than by themselves and portray their own actions as justifiable and their siblings' behavior as arbitrary and incomprehensible (Ross et al., 1999).

Studies of mood regulation provide further evidence of motivated remembering. Several theorists have suggested that individuals who are feeling dejected may attempt to improve their moods by selectively retrieving pleasant memories (Clark and Isen, 1982; Isen, 1987; Singer and Salovey, 1988). For example, Parrott and Sabini (1990) found that participants experiencing negative moods were more likely to recall pleasant events from their lives than were participants experiencing positive moods. Subsequent researchers suggested that certain personality traits may predispose individuals to alleviate negative affect by engaging in mood-incongruent recall (Smith and Petty, 1995; Boden and Baumeister, 1997; McFarland and Buehler, 1997). McFarland and Buehler found that only individuals who are especially inclined to focus on their feelings recruited more pleasant memories after a negative mood induction than after a neutral mood induction.

The research on motivation and recall might seem to imply that people can readily create a preferred past. If a woman wants to believe that she is shy, she can recall introverted behaviors. If the same person prefers to believe that she is outgoing, then she can readily recall extraverted behaviors. George Herbert Mead (1964) argued that memory is indeed this malleable and compared people's recollections to "escape fancies . . . in which we rebuild the world according to our hearts' desires" (pp. 348–349).

More recent research suggests that there are limits to people's ability to recall pasts consistent with their heart's desires. People's autobiographical memory includes more general memories as well as specific episodic memories (Conway and Playdell-Pearce, 2000; Klein et al., 2001, 2002). These general memories are summaries of repeated behaviors and events (e.g., going to nightclubs) and include personality traits (e.g., 'I am an introvert'). A person who arrives at an experiment with the generalized memory that she is an introvert is unlikely to discover suddenly that she is outgoing, even if she learns that extraversion is highly desirable (Sanitioso et al., 1990). Her remembering is constrained in two interrelated ways. She possesses a generalized belief that she is an introvert, and her stock of accessible episodic memories likely reflects her generalized belief. A woman who believes strongly that she is shy should be more able to access introverted behaviors, regardless of the experimenter's claims regarding the desirability of the trait.

Constraints on the effect of preferences on memory are clearly evident in research that assesses recall accuracy. Consider, for example, a study of university freshmen and sophomores' recollections of their grades over all 4 years of high school (Bahrick, 1998; Bahrick et al., 1996). Overall, their recall was quite good: Participants recalled 71% of their grades accurately. In short, students did not rewrite history to create a past in which they received straight As. Nonetheless, the errors they did make were systematic. Of the errors in recall, 81% were inflations of the actual grades (Bahrick, 1998). Also, participants' errors reflected their general academic ability. Students with high grade point averages recalled more of their Bs as As than did students in the lowest grade point average quartile. Thus outstanding students were more likely than mediocre students to infer a grade of A on those relatively few occasions that they misremembered their performance.

Studies of mood recall also provide evidence of both accuracy and bias. Retrospective reports of mood are accurate, in that recollections are correlated with earlier online reports of mood (e.g., Feldman Barrett, 1997) but biased by the rememberers' personality and beliefs about emotional experiences (Feldman Barrett, 1997; Robinson and Clore, 2002; Christensen et al., 2003).

Some theorists (e.g., Bahrick, 1998) associate schema-consistent errors with memory reconstruction and accurate recall with reproductive memory. Neither of these claims is necessarily true. Memory can be schema consistent because it is selective rather than reconstructive. For example, a person who is motivated to believe that she is outgoing may accurately retrieve episodes from her memory store (reproductive memory) but selectively retrieve memories that imply extroversion rather than introversion. As well, accurate recall can reflect memory reconstruction rather than the direct retrieval of information from memory. Suppose, for example, that some participants in the Bahrick et al. (1996) study believe that they are outstanding students. Also suppose that they cannot readily recall the grades that they received in several courses. These students might infer that they received high grades in these courses, because they view themselves as good students. If their academic self-assessment is reasonably valid, then they will be accurate in inferring high grades.

As Bartlett and others (e.g., Neisser, 1967) have argued, most autobiographical recall is probably a combination of reconstruction and reproductive remembering. The degree to which reconstruction or reproduction dominate will depend on a variety of factors, including the strength of encoding of the original events, the length of the time period between the event and the recall, the motivation to remember accurately, and the accessibility of relevant cognitive schemata (e.g., beliefs about of one's academic ability, personality, etc.) to guide recall.

## 2.47.4 Perceiving Change

We have argued that people are often cognitive conservatives who underestimate the degree to which their past feelings and beliefs differ from their present judgments. But people commonly perceive change in themselves on other dimensions, especially ability- and personality-related attributes on which improvement is possible. They also see changes in the world around them. Next, we review research showing that people are particularly inclined to see themselves as improving and the world as getting worse.

### 2.47.4.1 The Perception of Self-Improvement

In his autobiography, Arthur Koestler (1961) remarked that people are critical of their adolescent past self: "The gauche adolescent, the foolish young man that one has been, appears so grotesque in retrospect and so detached from one's own identity that one automatically treats him with amused derision. It is a callous betrayal, yet one cannot help being a traitor to one's past" (Koestler, 1961: p. 96). Wilson and Ross (2000, 2001) obtained research support for Koestler's observation but found that retrospective criticism of past selves extends well beyond adolescent selves. Across various samples (e.g., university students, middle-aged individuals, celebrity interviews) and in a variety of dimensions, people viewed themselves as steadily improving (Wilson and Ross, 2000, 2001). Moreover, people rated themselves as having improved more since a particular time in the past when that point was manipulated to seem long ago rather than recent (Wilson and Ross, 2001).

This perception of improvement is due, in part, to a retrospective tendency to find fault with earlier selves. The self that seems impressive today appears less remarkable in retrospect. Ironically, the tendency to disparage earlier selves seems to reflect concerns for self-enhancement (Ross and Wilson, 2000, 2001). People who are motivated to evaluate themselves favorably (e.g., those with high self-esteem) are particularly inclined to recall an inferior past self. Also, people do not see the same steady improvement in their peers that they see in themselves. By criticizing their own earlier selves, people can view their current self favorably by contrast.

Most of the studies of perceived self-improvement involve younger people. Would people in their 60s and 70s be more likely to see themselves as declining physically and cognitively? The answer is a qualified yes (McFarland et al., 1992; Ross and Wilson, 2001). Older people do view themselves as declining, but at a much slower rate than their peers (Ross and Wilson, 2002). When people cannot use retrospective comparisons to feel good about their current selves, they apparently engage in downward social comparisons to accomplish the same end.

If people are concerned with self-enhancement, why do they not simply praise their present selves rather than derogating past selves? There are advantages to deflating the past rather than inflating the present. If people continually boosted their current selves, their present self-regard might become so overstated as to be inconsistent with objective indicators (Baumeister, 1989). Appropriate judgments and choices depend on an accurate view of one's strengths and weaknesses. By derogating the past, individuals create an impression of improvement without greatly misrepresenting their present strengths and weaknesses.

Researchers have examined perceived improvement in a number of different contexts. Karney and his associates examined people's retrospective evaluations of satisfaction with their marriage (Karney and Coombs, 2000; Karney and Frye, 2002). Spouses underestimated their past contentment and often recalled it as lower than their present satisfaction. Although marital satisfaction decreased over the early years of marriage, individuals created the illusion of improvement by underestimating their former satisfaction levels. Studying prospective and retrospective trajectories of newlyweds' relationship satisfaction, Karney and Frye (2002) showed that this perception of improvement is linked to other indicants of relationship success. Spouses' retrospective reports of increases in relationship satisfaction predicted optimism about their relationship's future, independent of any actual change in satisfaction. In contrast, absolute levels of relationship satisfaction were unrelated to expectations. By derogating earlier aspects of themselves and their relationships, people can make their current state seem superior by comparison and foster optimism about the future.

People can also use retrospective reevaluation to detect a silver lining in their personal tragedies. McFarland and Alvaro (2000) asked individuals who had experienced a tragedy to evaluate what they were like prior to the episode. Some participants were reminded of the disturbing episode before completing the evaluation, and others were not reminded. Participants who were reminded provided lower evaluations of their earlier, pretrauma selves. In addition, people were more critical of former selves after being reminded of severely rather than mildly disturbing experiences. Individuals may reduce the negative impact of a trauma by focusing on how it led to growth or positive outcomes for the self.

Retrospective overestimation of change is especially likely when people experience a circumstance that they expect to produce change on certain dimensions, but that in reality has minimal impact on those qualities. Self-help programs are a context in which people's hopes of change are likely to be disappointed. Participants tend to suppose that self-help programs are beneficial, but formal evaluations that include placebo control conditions typically show the programs to be of little value (Polivy and Herman, 1983; Ross and Conway, 1986). Conway and Ross (1984) studied the relation between memory and expectations for change in the context of a study-skills program. They asked university students to evaluate their study skills and then randomly assigned half of them to a study-skills program that lasted several weeks and the remaining half to a control condition. Although participants in the treatment program expected to improve their grades, their program, like most other study-skills courses, was ineffective. At the conclusion of the course, participants in the treatment and control conditions were asked to recall their original ratings of their study skills. They were reminded that the researcher had their initial ratings and would assess the accuracy of their recall. Participants who took the course remembered their preprogram ratings as being worse than they had reported initially. In contrast, control participants, who had not received the program, exhibited no systematic bias in recall. The biased recollections of participants in the study skills course would support their belief that the program had improved their skills. More generally, a tendency to revise the past in order to claim personal improvement may explain why many individuals report that they benefit from ineffective therapies and self-improvement programs (Conway and Ross, 1984).

## 2.47.5 Perceiving Change in Society

### 2.47.5.1 Mistaking Change in Self for Change in the World

Although people tend to see themselves as improving, they regard their society as deteriorating. Moral standards are weakening, crime rates are rocketing, and the quality of popular music and films is declining (Eibach et al., 2003). This view of societal deterioration can be found in most cultures and eras: "Virtually every culture past or present has believed that men and women are not up to the standards of their parents and forbears" (Herman, 1997: p. 13). There are a host of plausible explanations for the perceived decline (Eibach et al., 2003; Ross, 1989), but Eibach and his colleagues tested a particularly intriguing one: Change in the self is mistaken for change in the world. According Eibach et al. (2003), when people experience life changes their concerns and interests shift. For example, new parents are more sensitive to possible dangers to children, including crimes. In the face of an actual decline in crime rates, new parents are more likely to perceive crime rates as increasing than are respondents who did not become parents during that interval (Eibach et al., 2003). Similarly, dieters perceive an increase in advertising for unhealthy foods in the previous decade, relative to nondieters (Eibach et al., 2003).

Why are the perceived social changes so often negative? Eibach et al. (2003) provide a number of possible answers to this question. For example, they quote Herman (1997), who notes that as older people's cognitive and physical abilities decline with age, they might confuse their own diminishing powers with decline in the world. Also, older people's greater familiarity with the social mores, films, and music of their youth might enhance their appreciation of the good old days.

#### 2.47.5.2 Group Status and the Perception of Social Change

Eibach and his associates have conducted other research on how different groups in society, especially the haves and have-nots, evaluate progress toward social equality. Generally, privileged groups see more progress than disadvantaged groups do. Men report that the income gap between men and women has declined more in the previous decade than women do; White Americans view the conditions for Blacks as improving more over the previous few years than Blacks do (Eibach and Keegan, 2006). Eibach and Ehrlinger (2006) suggest that advantaged and disadvantaged groups use different reference points to evaluate change. White respondents compare the treatment of Blacks in the past to the treatment of Blacks in the present and report progress. Black respondents compare their current outcomes to the outcomes they should receive (equality with Whites) and report that they still have a long way to go. Both groups are right: a half full glass is also half empty.

Why do more privileged and less privileged groups select different reference points? One answer is that members of the more privileged group are concerned about losing their advantages, and so are especially sensitive to how each group's status has changed over time. In contrast, members of less privileged groups are primarily interested in achieving equality; therefore they focus on the gap between where they are and where they need to be to attain equality (Eibach and Keegan, 2006).

## 2.47.6 Subjective Time and Point of View

Although most studies have concerned the content of autobiographical memory, researchers have examined two additional properties of memory with social psychological implications: People's feelings of temporal proximity to past events and their visual perspective on the remembered events.

### 2.47.6.1 Subjective Time

The subjective experience of time is related to clock and calendar time – last week feels farther away than yesterday – but it is not the same thing (James, 1950; Brown et al., 1985; Block, 1989; Wilson and Ross, 2003). Of particular interest here is that differences in the evaluative implications of past episodes influence people's feelings of proximity to those events (Ross and Wilson, 2000, 2002). To protect their current self-regard, people are motivated to feel farther from past failings than from achievements. In one study (Ross and Wilson, 2002), university students were asked to remember the course in the previous semester in which they received either their best or worst grade. After reporting their grade, participants indicated whether the course 'felt' recent or far away. Participants felt farther away from a course in which they obtained a relatively low grade, even though the actual passage of time did not differ in the two conditions. Subsequent research indicated that this asymmetry reveals both a tendency to pull favorable outcomes forward in subjective time and push inauspicious outcomes backward (Ross and Wilson, 2002), though the latter effect may be somewhat stronger.

Meichenbaum (2006a,b) examined the relation of the subjective experience of time to psychological disorders such as posttraumatic stress disorder (PTSD). According to Meichenbaum, these disorders reflect a flawed self-narrative. A self-narrative is the internal autobiography people construct to make sense of the life they have lived so far.

Meichenbaum suggests that the trauma memories of individuals with PTSD are stuck in the present. Individuals with persistent PTSD engage in internal conversations about ongoing threats, ruminate on the negative impact of the trauma, and actively try to suppress thoughts and emotions related to the trauma. The trauma takes center stage and is characterized as the most important theme in the life story.

To address the effects of PTSD, Meichenbaum advises therapists to help patients reframe their traumatic memories into historical narratives that have a distinct beginning, middle, and end. Patients with PTSD should incorporate traumatic memories into the self-narrative in such a way that the events are seen as a small part of the life story, rather than an ongoing theme. Meichenbaum also suggests that therapists emphasize the distinction between present and past and position the traumatic memory firmly in the past.

### 2.47.6.2 Point of View

Nigro and Neisser (1983) reported that individuals recall events from either a first-person or a third-person visual perspective. When people adopt a first person perspective, they view the event through their own eyes. When people assume a third-person point of view, they view the event as an outside observer who is watching the actions of the past self. The fundamental attribute of a third-person memory is that individuals can see themselves in the recollection.

Like subjective time, point of view is a variable that relates to 'how' people remember, rather than 'what' they remember. Moreover, like subjective time, point of view is associated with actual temporal distance, memory content, and self-concept. Older memories are more likely to be viewed from a third-person point of view (Nigro and Neisser, 1983). Memory perspective is flexible, however, and the content of the memory also affects the perspective adopted (Nigro and Neisser, 1983). For example, participants were more likely to use a first-person perspective when they focused on the emotional content of a memory, rather than its objective circumstances (Nigro and Neisser, 1983).

Libby and Eibach (2002; Libby et al., 2005) related the visual perspective of autobiographical memories to the self-concept. Individuals were more likely to invoke a first-person perspective when recalling actions consistent with their current self-concept. For example, participants who were induced to feel religious (by means of a biased questionnaire) were highly likely to recall a religious memory from a first-person perspective. Participants who were encouraged to feel irreligious were significantly more likely to report that they viewed a religious memory from a third-person perspective (Libby and Eibach, 2002). In another study (Libby et al., 2005), participants were randomly assigned to recall the same episode from either a first-person or third-person perspective. Participants who invoked a third-person perspective reported that they had changed more since the time of the episode. A third-person perspective seems to operate as a distancing mechanism, leading individuals to perceive that a past self is a different person than the current self.

Some clinicians have advocated use of the third-person perspective in therapy. Lawrence (1990) suggested that a patient speaking in the third person is able to adopt a more detached perspective on memories. Lawrence claimed that, as a result, third-person analysis yields less guilt and fewer defensive justifications. Similar to pushing events back in subjective time, the use of a third-person perspective involves reducing the psychological threat of negative experiences through distancing, rather than through forgetting or denial.

## 2.47.7 Memory in a Social Context

### 2.47.7.1 Collaborative Memory

Although psychologists generally study remembering as a solitary cognitive activity, everyday remembering is frequently collaborative. For example, spouses depend on each other's memories as they try to recall phone numbers or names (Wegner et al., 1991). Intuitively, it seems likely that collaboration would improve recall, and research confirms this belief: Two people, remembering together, recall more than either individual would recall alone (e.g., Vollrath et al., 1989; Weldon, 2001).

There are two obvious reasons why collaboration might improve memory. First, group memory might be better simply because two individuals are remembering rather than one. Alternatively, collaboration might bring forth memories that would not arise during solitary remembering. If such synergy occurs, two individuals would remember more together than they would if they pooled their individual recollections. To clarify this distinction, consider two spouses independently remembering a shopping list. On his own, the man remembers items a, b, c, and d; meanwhile, his wife remembers a, b, e, and f. Alone, they each remember four items. If they pooled their individual recollections, they would together recall six nonredundant items (a, b, c, d, e, f). What if, instead of recalling the shopping list separately, they had recalled it together? Collaboration provides the opportunity for cross-cuing: The recollections of one person can offer cues that help another person remember information (Meudell et al., 1995). It seems plausible, then, that collaborative recall would generally exceed the sum of individual recollections provided by group members.

To examine whether collaboration produces better memory than pooled individual recollections, researchers include three conditions: individuals remembering alone, individuals remembering together, and nominal group recall. Nominal groups are groups in name only. Participants remembering alone are coupled, often randomly, and their recall is pooled. The recall score of a nominal group is the total amount of nonredundant information in the pooled recall. When these procedures are followed, the findings are consistent: Nominal group recall exceeds collaborative recall, which in turn surpasses individual memory (e.g., Basden et al., 1997; Weldon and Bellinger, 1997; Finlay et al., 2000; Weldon, 2001; Ross et al., 2004).

Labeled collaborative inhibition (Weldon and Bellinger, 1997), the finding that nominal recall outstrips collaborative recall has been obtained in dyads of strangers, friends, and married couples, and in elderly couples as well as college students. Although collaborative inhibition sometimes declines in well-acquainted groups, it is not reversed. Collaborating friends or spouses recall no more information than nominal groups, and they usually recall less (Andersson and Ronnberg, 1995; Johansson et al., 2000; Gould et al., 2002; Ross et al., 2004). Evidently, the cross-cuing that occurs during collaboration produces inadequate retrieval cues and interference rather than emergent memories (Meudell et al., 1995; Finlay et al., 2000). While listening to someone else's recollections, group members might forget their own memories or be prevented from trying to remember (Diehl and Stroebe, 1987). Also, idiosyncratic, self-generated retrieval cues are often better triggers for one's own memories than cues provided by another person (Basden et al., 1977; Meudell et al., 1995; Andersson et al., 2006). To the extent that collaboration inhibits self-generated retrieval cues, recall is likely to suffer.

So should spouses or work colleagues collaborate when trying to remember information in everyday settings, for example, the items in a list? The answer is yes for three reasons. First, collaborative recall is better than individual recall, even if it is not superior to pooled nominal group recall. Second, over time well-acquainted groups develop integrated systems of memory storage and retrieval for some everyday memory tasks (Wegner, 1986). They learn to divide the labor on memory tasks based on personal expertise (e.g., the travel agent spouse remembers to book summer vacations) and gender-role stereotypes (e.g., the man remembers when the car needs an oil change). Because of this division, there is no reason for spouses to try to remember everything. As long as they know what type of information their partners know, they can call on them when needed.

Finally, collaboration is useful because it can help reduce mistakes in memory even when it does not increase the amount of true memory recalled. A measure of mistakes, or false positives, is omitted in many studies of collaborative recall because the frequency of errors is low in the types of memory tasks typically used in this research (Ross et al., 2004). Using everyday memory tasks in which false memories were quite common, Ross et al. (2004) found that collaborative groups of older adults reported fewer errors in free recall than did nominal groups or individuals recalling alone. A recent study shows that collaboration produces a similar reduction in errors of younger (under age 40) participants (Ross et al., unpublished data).

Why might collaboration reduce memory errors? Any particular error is often unique to an individual, reflecting his or her knowledge, beliefs, and associative linkages between items in long-term memory (Ross et al., 2004). When errors are idiosyncratic, a rememberer's partner can exercise a kind of quality control by inspecting the memory, assessing its accuracy, and expunging false recall.

A reduction in false recall could be especially important for older people, who tend to recall more false memories than their younger counterparts (Jacoby and Rhodes, 2006). Relative to younger adults, older individuals are more likely to be misled by false information, more prone to source memory errors, and more confident of the accuracy of their false memories (Hashtroudi et al., 1989; Jacoby, 1999; Karpel et al., 2001; McCabe and Smith, 2002; Kelley and Sahakyan, 2003; Jacoby et al., 2005). There is not much research on techniques that might help older people reduce such errors. Collaboration has the advantage of being a readily available strategy in everyday life.

### 2.47.7.2 Controlling and Transmitting Memories

The research discussed in the preceding section on collaborative memory features two individuals remembering together at the same time. But memory is often collaborative in another sense. Memories are transmitted from person to person and from generation to generation. Much of what we remember we have learned from others rather than experienced directly. This type of remembering is evident in people's knowledge of the history and origins of their countries. As with individual memory, prior events or beliefs that contradict current ideas and values are sometimes erased from the history or altered so as to be consistent with present understandings (Goody and Watt, 1968; Ong, 1982). For example, when the British arrived in Ghana in the early part of the twentieth century, they found that the state of Gonja was divided into seven territories, each ruled by its own chief (Goody and Watt, 1968). When British authorities asked them to explain their system, the Gonja revealed that the founder of their state, Ndewura Jakpa, had fathered seven sons. Jakpa divided the land so that each son ruled one territory. Shortly after the British arrived, two of the seven states in Gonja disappeared as a result of changes in boundaries. Sixty years later, oral historians again recorded the myths of state. In the updated version, Ndewura Jakpa had only five sons; the Gonja made no mention of the founders of the two territories that had vanished from the scene.

In literate societies, individuals also revise history, especially in response to changing knowledge, goals, and political regimes (Greenwald, 1980). People interpret the past in terms of the present, and therefore "every generation rewrites its history" (Mead, 1964: p. 351). Some of the revisions involve efforts to improve the past. Stories of atrocities and wrongs committed by compatriots are often excluded from a nation's history textbooks and from popular culture (Hein and Selden, 2000). As Blight (2001) remarked with respect to memory of the American Civil War, "deflections and evasions, careful remembering and necessary forgetting, and embittered and irreconcilable versions of experience are all the stuff of historical memory" (Blight, 2001: p. 5).

We do not have to look to history to find archival evidence of people's efforts to improve the past. We can look at our own discipline, psychology. Research findings constitute the core of scientific psychology. Are past results described accurately in secondary sources, such as review articles and book chapters of the sort you are reading? Not always. When writing about past research, psychologists sometimes describe the results or procedures in ways that magnify the strength of the findings (Berkowitz, 1971; Loftus, 1974; Harris, 1979; Vicente and Brewer, 1993), as well as allow their theoretical preferences to guide their summaries and interpretations of past research (Berkowitz, 1971; Harris, 1979; Vicente and Brewer, 1993). Comparable distortions occur in the literature of other sciences (Vicente and Brewer, 1993).

It is also not difficult to find evidence of distortions in the media that could contribute to distortions in memory. The media play a role in communicating the words of famous individuals to society at large and therefore in producing memories of their statements. Misquotations in newspapers and other print media provide intriguing examples of historical revision (Keyes, 1992). For example, baseball manager Leo Durocher is credited with saying "Nice guys finish last." He really said, "The nice guys are all over there. In seventh place." The quote became punchier and pithier with repeated retelling. A second notable misquotation is associated with the comedian W. C. Fields. Fields is renowned for saying, "Any man who hates dogs and children can't be all bad." Fields did not say it. Leo Rosten said it about Fields when he introduced the comedian at a banquet. Keyes (1992) provided many other examples of quotations that change or are ascribed to the wrong person over time. Keyes was able to trace the source of the various quotations because he had access to documentary records.

Ordinary people do not write textbooks or journal articles or get quoted in the media all that often. But they do transmit information and memories across generations through socialization, stories, and teaching. Sometimes this information is transmitted precisely and remembered verbatim. For example, children memorize the times tables and the spelling of words, while anatomy students memorize the names and locations of brain structures. In these cases, approximations are not good enough. Even though the words are very similar, you cannot write golf if you mean gulf. In most contexts, however, children and adults are not required to recall or transmit a verbatim memory. Daily remembering typically involves recalling the meaningful gist of episodes rather than exquisite detail. Moreover, as information is transmitted from individual to individual, it changes. People adjust their reports of their memories in response to their listeners' status, age, interests, knowledge, and attitudes (Brown and

Levinson, 1978; Higgins and Rholes, 1978; Cansler and Stiles, 1981; DePaulo and Coleman, 1986; Schlenker and Weigold, 1992; Kashima, 2000; Thompson et al., 2000; Lyons and Kashima, 2003). The recipients of the information then take ownership of it by making it more consistent with their current beliefs and knowledge (Bartlett, 1932).

The study of rumors provides an intriguing example of how information is constructed and transmitted. Rumors often emerge when information is scarce but people feel a need to know (Allport and Postman, 1947). Consider, for example, rumors that occurred after Hurricane Katrina struck the Gulf Coast region of the United States (Rosenblatt and Rainey, 2005). The hurricane destroyed lines of communication and the associated ability to obtain direct news reports from the Gulf Coast. Most news reports were based, at best, on secondhand accounts. News agencies reported grossly exaggerated stories. In the first few days after the hurricane struck, news reports implied that the city had descended into chaos: Senseless looting was prevalent, snipers were randomly shooting people from rooftops, and gangs were roving the streets in murderous rampages. Most of these rumors were either exaggerations or completely false (Rosenblatt and Rainey, 2005).

Bartlett (1932) attempted to capture this process of rumor transmission with his method of serial reproduction. In Bartlett's research, the first participant in a chain read a fairly obscure and confusing passage (e.g., 'The War of the Ghosts') and recalled the passage after a 15-min delay. A second person read the first person's account and recalled it; a third person read the second person's account, and so on. Bartlett found that verbatim recall of the passage was rare. Participants commonly omitted unusual elements and added connections to make sense of the material. Bartlett took these findings as evidence for a reconstructive view of memory. It is also likely that the process of communication influenced recall of the story. To be clear and comprehensible, participants might alter the information that they transmit.

Along the same lines, Allport and Postman (1947) had the first participant in a six- or seven-person chain view a picture. The first person served as an "eyewitness" and was the only person in the chain to see the picture. The initial person described the picture (while viewing it) to a second person. This second person then transmitted what he or she remembered to a third person and so forth. Participants were told to listen carefully and transmit what they heard as "exactly as possible" (Allport and Postman, 1947: p. 66).

In contrast to Bartlett, who used obscure stories as stimuli in his studies, Allport and Postman used pictures that were not difficult to understand. The pictures contained everyday scenes such as people seated on a subway. Nonetheless, Allport and Postman obtained results similar to Bartlett's. They found that descriptions of the pictures were leveled and sharpened as recall moved along the chain. Leveling involves reducing the amount of detail, and sharpening refers to emphasizing just a few core elements. As rumors are transmitted, they change from more elaborate stories (e.g., desperate residents of New Orleans breaking into stores seeking supplies) to a core theme (e.g., senseless looting).

Allport and Postman (1947) used several pictures, but their most famous scene portrayed a Black and White man having a confrontation on a subway train. In the original scene, the White man held a knife. Early in the chains, participants accurately recalled that the White man possessed the knife. As the description of the picture was passed along the chains, however, the knife sometimes ended up in the hands of the Black man. The stereotype of aggressive Black men apparently influenced memory further down the chain. Similar to Barlett, Allport and Postman did not provide detailed descriptions of their findings. It is unclear in how many chains the knife changed hands.

Recent media reporting of world events may have replicated this finding. Many have argued that the news reports of senseless looting in New Orleans reflect similar racial stereotyping (Rosenblatt and Rainey, 2005). News reports portrayed Black Americans breaking into stores looking for necessary supplies and, occasionally, expensive consumer items (Rosenblatt and Rainey, 2005). Often incidents of people stealing expensive products such as plasma televisions were emphasized more than incidents of people appropriating diapers, toothbrushes, and canned goods (Rosenblatt and Rainey, 2005). Negative aspects of the Black stereotype likely contributed to how events were reported in the media and remembered by a non-Black audience.

Gilovich (1987; Study 1) applied the method of serial reproduction to person perception. The first person in the chain watched a videotape of a male or female student describing transgressions they had committed, along with mitigating circumstances that helped explain their actions. Participants then evaluated the target on several dimensions (e.g., generous/selfish) and described what they had seen on the videotape to another person. They were told to provide a description that would permit a listener "to determine what this person did and what this person was like" (Gilovich, 1987: p. 63). The second-generation person evaluated the target after hearing the description. Interestingly, second-generation participants evaluated the transgressor more negatively than did the first people in the chain. This difference arose because first-generation participants were more likely to take mitigating circumstances into account. In leveling and sharpening their report, however, first-generation participants underemphasized mitigating circumstances; as a result, such conditions had less of an impact on the judgments of second-generation participants.

The Gilovich study has intriguing practical implications. Because the public rarely has direct exposure to world events, public opinion is influenced by how events are depicted in the media. And the leveling and sharpening that occurs in the process of reporting is likely to affect public opinion. There is evidence, for example, that media reports affect judgments of the criminal justice system. Public opinion in Canada and elsewhere often evaluates criminal sentences as too light (Roberts and Doob, 1990). In examining this phenomenon, Roberts and Doob found that media reports of criminal trials are leveled and sharpened. Journalists often omit mitigating circumstances that judges take into account during sentencing. In one study conducted by Roberts and Doob (1990), individuals who read actual court documents supported a lighter sentencing decision than did those who read a newspaper description of the sentencing decision.

## 2.47.8 Creating Memories

The issues that we have discussed concerning the transmission of memories come into focus in media portrayals of historical figures. Novelists, dramatists, and screenwriters sometimes deliberately blur the line between historical truth and fiction. They may sometimes do this for political reasons; for example, Shakespeare tailored the facts in his histories to suit the preferences of the Tudor monarchs of his day. Authors may also rewrite history to increase dramatic tension and maintain an audience's interest. In his play *Amadeus*, Peter Shaffer's depiction of the characters of Mozart and Salieri, and of Salieri's possible complicity in Mozart's death, is effective drama but questionable history. For many members of the audience, Shaffer's account may provide the primary source of information on Mozart's life story.

Presumably most people attend films or live theater to be entertained rather than to obtain a history lesson. When the tale is set in an historical context, however, they may believe that they have received both. Audiences who are unaware of alternative accounts may accept such stories as authentic. In this manner, the media help shape people's collective memories.

The revision of history to accomplish particular objectives is not limited to professional writers, the media, or scientists. As we have emphasized in this chapter, it is also a hallmark of everybody's efforts to recall and communicate their pasts. In comparison to professional writers who derive their historical stories from written records, individuals may be less aware of their alterations as they use their present knowledge, beliefs, and goals to construct their own histories. In this sense, people's personal recollections are comparable to the oral traditions of nonliterate societies.

It is useful and normal for people to create pasts that satisfy their current needs. As Bartlett (1932) and Mead (1964) stressed, the past is a resource that people can use and adapt for current purposes. People can get into trouble, however, if they underestimate the fallibility of their own memories. Perhaps the lesson of social psychological research on memory is not that people should be less creative but that individuals should be aware of the degree to which they rewrite their own histories.

## References


Allport GW and Postman L (1947) *The Psychology of Rumor*. New York: Holt Rinehart and Winston.

Andersson J and Ronnberg J (1995) Recall suffers from collaborations: Joint recall effects of friendship and task complexity. *Appl. Cognit. Psychol.* 9: 199–211.

Andersson J, Hitch G, and Meudell P (2006) Effects of the timing and identity of retrieval cues in individual recall: An attempt to mimic cross-cueing in collaborative recall. *Memory* 14: 94–103.

Bahrick HP (1998) Loss and distortion of autobiographical memory content. In: Thompson CP, Herrmann DJ, Bruce D, Read JD, and Payne DG (eds.) *Autobiographical Memory: Theoretical and Applied Perspectives*, pp. 69–78. Mahwah, NJ: Erlbaum.

Bahrick HP, Hall LK, and Berger SA (1996) Accuracy and distortion in memory for high school grades. *Psychol. Sci.* 7: 265–271.

Bartlett FC (1932) *Remembering: A Study in Experimental and Social Psychology*. Cambridge: Cambridge University Press.

Basden DH, Basden DR, and Galloway BC (1977) Inhibition with part-list cueing: Some tests of the item-strength hypothesis. *J. Exp. Psychol. Hum. Learn. Mem.* 3: 100–108.

Basden DH, Basden DR, Bryner S, and Thomas RL III (1997) A comparison of group and individual remembering: Does collaboration disrupt retrieval strategies? *J. Exp. Psychol. Learn. Mem. Cogn.* 23: 1176–1191.

Baumeister RF (1989) The optimal margin of illusion. *J. Social Clin. Psychol.* 8: 176–189.

Baumeister RF, Stillwell A, and Wotman SR (1990) Victim and perpetrator accounts of interpersonal conflict: Autobiographical narratives about anger. *J. Personality Social Psychol.* 59: 994–1005.

Baumeister RF, Wotman SR, and Stillwell AM (1993) Unrequited love: On heartbreak, anger, guilt, scriptlessness, and humiliation. *J. Personality Social Psychol.* 64: 377–394.

Bellezza FS (1984) The self as a mnemonic device: The role of internal cues. *J. Personality Social Psychol.* 47: 506–516.

Berkowitz L (1971) Reporting an experiment: A case study in leveling, sharpening, and assimilation. *J. Exp. Soc. Psychol.* 7: 237–243.

Blight DW (2001) *Race and Reunion: The Civil War in American Memory*. London: Belknap Press.

Block RA (1989) Experiencing and remembering time: Affordances, context, and cognition. In: Levin I and Zakay D (eds.) *Advances in Psychology, vol. 59. Time and Human Cognition: A Life-Span Perspective*, pp. 333–363. Amsterdam: North-Holland.

Bluck S (2003) Autobiographical memory: Exploring its functions in everyday life. *Memory* 11: 113–123.

Boden JM and Baumeister RF (1997) Repressive coping: Distraction using pleasant thoughts and memories. *J. Personality Social Psychol.* 73: 45–62.

Brown NR, Rips LJ, and Shevell SK (1985) The subjective dates of natural events in very-long-term memory. *Cogn. Psychol.* 17: 139–177.

Brown P and Levinson S (1978) Universals in language usage: Politeness phenomena. In: Goody EN (ed.) *Questions and Politeness: Strategies in Social Interaction*, pp. 260–289. London: Cambridge University Press.

Cansler DC and Stiles WB (1981) Relative status and interpersonal presumptuousness. *J. Exp. Soc. Psychol.* 17: 459–471.

Christiansen TC, Wood JV, and Barrett Feldman L (2003) Remembering everyday experience through the prism of self-esteem. *Personality Social Psychol. Bull.* 29: 51–62.

Clark MS and Isen AM (1982) Toward understanding the relationship between feeling states and social behavior. In: Hastorf AH and Isen AM (eds.) *Cognitive Social Psychology*, pp. 73–108. New York: Elsevier/North Holland.

Conway MA and Pleydell-Pearce CW (2000) The construction of autobiographical memories in the self-memory system. *Psychol. Rev.* 107: 261–288.

Conway M and Ross M (1984) Getting what you want by revising what you had. *J. Personality Social Psychol.* 47: 738–748.

Dawson NV, Arkes HR, Siciliano C, et al. (1988) Hindsight bias: An impediment to accurate probability estimation in clinicopathologic conferences. *Med. Decision Making* 4: 259–264.

DePaulo BM and Coleman LM (1986) Talking to children, foreigners, and retarded adults. *J. Personality Social Psychol.* 51: 945–959.

Diehl M and Stroebe W (1987) Productivity loss in brainstorming groups: Toward the solution of a riddle. *J. Personality Social Psychol.* 53: 497–509.

Eibach RP and Ehrlinger J (2006) ''Keep your eyes on the prize'': Reference points and racial differences in assessing progress toward equality. *Personality Social Psychol. Bull.* 32: 66–77.

Eibach RP and Keegan T (2006) Free at last? Social dominance, loss aversion, and white and black Americans' differing assessments of racial progress. *J. Personality Social Psychol.* 90: 453–467.

Eibach RP, Libby LK, and Gilovich TD (2003) When change in the self is mistaken for change in the world. *J. Personality Social Psychol.* 84: 917–931.

Eid M and Diener E (2001) Norms for experiencing emotions in different cultures: Inter- and intranational differences. *J. Personality Social Psychol.* 81: 869–885.

Epstein S (1973) The self-concept revisited: A theory of a theory. *Am. Psychol.* 28: 404–416.

Erikson EH (1968) *Identity: Youth and Crisis*. Oxford: Norton and Co.

Feldman Barrett L (1997) The relationship among momentary emotion experiences, personality descriptions, and retrospective ratings of emotion. *Personality Social Psychol. Bull.* 23: 1100–1110.

Finlay F, Hitch GJ, and Meudell PR (2000) Mutual inhibition in collaborative recall: Evidence for a retrieval-based account. *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 1556–1567.

Fischhoff B and Beyth R (1975) ''I knew it would happen'': Remembered probabilities of once-future things. *Org. Behav. Hum. Perform.* 13: 1–16.

Gilovich T (1987) Secondhand information and social judgment. *J. Exp. Soc. Psychol.* 23: 59–74.

Goethals GR and Reckman RF (1973) The perception of consistency in attitudes. *J. Exp. Soc. Psychol.* 9: 491–501.

Goody J and Watt I (1968) The consequences of literacy. In: Goody J (ed.) *Literacy in Traditional Societies*, pp. 27–68. New York: Cambridge University Press.

Gould ON, Osborn C, Krein H, and Mortenson M (2002) Collaborative recall in married and unacquainted dyads. *Int. J. Behav. Dev.* 26: 36–44.

Gramzow RH and Willard G (2006) Exaggerating current and past performance: Motivated self-enhancement versus reconstructive memory. *Personality Social Psychol. Bull.* 32: 1114–1125.

Greenwald AG (1980) The totalitarian ego: Fabrication and revision of personal history. *Am. Psychol.* 35: 603–618.

Harris B (1979) Whatever happened to Little Albert? *Am. Psychol.* 34: 151–160.

Hashtroudi S, Johnson MK, and Chrosniak LD (1989) Aging and source monitoring. *Psychol. Aging* 4: 106–112.

Hein L and Selden M (2000) *Censoring History: Citizenship and memory in Japan, Germany, and the United States*. Armonk, NY: ME Sharpe.

Herman A (1997) *The Idea of Decline in Western History*. New York: Free Press.

Higgins ET and Rholes WJ (1978) ''Saying is believing'': Effects of message modification on memory and liking for the person described. *J. Exp. Soc. Psychol.* 4: 363–378.

Hoffrage U, Hertwig R, and Gigerenzer G (2000) Hindsight bias: A by-product of knowledge updating? *J. Exp. Psychol. Learn. Mem. Cogn.* 26: 566–581.

Isen AM (1987) Positive affect, cognitive processes, and social behavior. In: Berkowitz L (ed.) *Advances in Experimental Social Psychology,* vol. 20, pp. 203–253. San Diego: Academic Press.

Jacoby LL (1999) Deceiving the elderly: Effects of accessibility bias in cued-recall performance. *Special Issue: Cognitive Neuropsychology of False Memories. Cogn. Neuropsychol.* 16: 417–436.

Jacoby LL and Rhodes MG (2006) False remembering in the aged. *Curr. Dir. Psychol. Sci.* 15: 49–53.

Jacoby LL, Bishara AJ, Hessels S, and Toth JP (2005) Aging subjective experience, and cognitive control: dramatic false remembering by older adults. *J. Exp. Psychol. Gen.* 134: 131–148.

James W (1890/1950) *Principles of Psychology*. New York: Dover.

Johansson O, Andersson J, and Ronnberg J (2000) Do elderly couples have a better prospective memory than other elderly people when they collaborate? *Appl. Cogn. Psychol.* 14: 121–133.
Kandel ER (2006) *In Search of Memory*. New York: Norton.
Karney BR and Coombs RH (2000) Memory bias in long-term close relationships: Consistency or improvement? *Personality Social Psych. Bull.* 26: 959–970.
Karney BR and Frye NE (2002) ''But we've been getting better lately'' Comparing prospective and retrospective views of relationship development. *J. Personality Social Psychol.* 82: 222–238.
Karpel ME, Hoyer WJ, and Toglia MP (2001) Accuracy and qualities of real and suggested memories: Nonspecific age differences. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 56B: 103–110.
Kashima Y (2000) Maintaining cultural stereotypes in the serial reproduction of narratives. *Personality Social Psychol. Bull.* 26: 594–604.
Kelley CM and Sahakyan L (2003) Memory, monitoring, and control in the attainment of memory accuracy. *J. Mem. Lang.* 48: 704–721.
Keyes R (1992) *Nice Guys Finish Seventh: False Phrases Spurious Sayings, and Familiar Misquotation*. New York: Harper Collins.
Kitayama S and Markus HR (1994) Introduction to cultural psychology and emotion research. In: Kitayama S and Markus HR (eds.) *Emotion and Culture: Empirical Studies of Mutual Influence*, pp. 1–19. Washington DC: American Psychological Association.
Klein SB, Cosmides L, Tooby J, and Chance S (2001) Priming exceptions: A test of the scope hypothesis in naturalistic trait judgments. *Soc. Cogn.* 19: 443–468.
Klein SB, Cosmides L, Tooby J, and Chance S (2002) Decisions and the evolution of memory: Multiple systems, multiple functions. *Psychol. Rev.* 109: 306–329.
Koestler A (1961) *Arrow in the Blue, an Autobiography*. New York: Macmillan.
Kunda Z (1990) The case for motivated reasoning. *Psychol. Bull.* 108: 480–498.
Lawrence L (1990) On the theory and application of third person analysis in the practice of psychotherapy. *J. Mind Behav.* 11: 97–104.
Levine LJ (1997) Reconstructing memory for emotions. *J. Exp. Psychol. Gen.* 126: 165–177.
Libby LK and Eibach RP (2002) Looking back in time: Self-concept change affects visual perspective in autobiographical memory. *J. Personality Social Psychol.* 82: 167–179.
Libby LK, Eibach RP, and Gilovich T (2005) Here's looking at me: The effect of memory perspective on assessments of personal change. *J. Personality Social Psychol.* 88: 50–62.
Loftus EF (1974) On reading the fine print. *Q. J. Exp. Psychol.* 27: 324.
Lyons A and Kashima Y (2003) How are stereotypes maintained through communication? The influence of stereotype sharedness. *J. Personality Social Psychol.* 85: 989–1005.
Markus HR and Kitayama S (1994) The cultural construction of self and emotion: Implications for social behavior. In: Kitayama S and Marbus HR (eds.) *Emotion and Culture: Empirical Studies of Mutual Influence*, pp. 89–130. Washington, DC: American Psychological Association.
McAdams DP (1982) Experiences of intimacy and power: Relationships between social motives and autobiographical memory. *J. Personality Social Psychol.* 42: 292–302.
McAdams DP (2001) The psychology of life stories. *Special issue: Autobiographical memory. Rev. Gen. Psychol.* 5: 100–122.
McAdams DP, Hoffman BJ, Mansfield ED, and Day R (1996) Themes of agency and communion in significant autobiographical scenes. *J. Pers.* 64: 339–377.
McCabe DP and Smith AD (2002) The effect of warnings on false memories in young and older adults. *Mem. Cognit.* 30: 1065–1077.
McFarland C and Alvaro C (2000) The impact of motivation on temporal comparisons: Coping with traumatic events by perceiving personal growth. *J. Personality Social Psychol.* 79: 327–343.
McFarland C and Buehler R (1997) Negative affective states and the motivated retrieval of positive life events: The role of affect acknowledgment. *J. Personality Social Psychol.* 73: 200–214.
McFarland C and Ross M (1987) The relation between current impressions and memories of self and dating partners. *Personality Social Psychol. Bull.* 13: 228–238.
McFarland C, Ross M, and Giltrow M (1992) Biased recollections in older adults: The role of implicit theories of aging. *J. Personality Social Psychol.* 62: 837–850.
Mead GH (1929/1964) *Selected Writings: George Herbert Mead*. Indianapolis: Bobbs-Merrill.
Meichenbaum D (2006a) Resilience and posttraumatic growth: A constructive narrative perspective. In: Calhoun LG and Tedeschi RG (eds.) *Handbook of Posttraumatic Growth: Research and Practice*, pp. 355–367. Mahwah, NJ: Erlbaum.
Meichenbaum D (2006b) Trauma and suicide: A constructive narrative perspective. In: Ellis TE (ed.) *Cognition and Suicide: Theory, Research, and Therapy*, pp. 333–353. Washington DC: American Psychological Association.
Meudell PR, Hitch GJ, and Boyle M (1995) Collaboration in recall: Do pairs of people cross cue each other to produce new memories? *Q. J. Exp. Psychol.* 48: 141–152.
Murray SL and Holmes JG (1993) Seeing virtues in faults: Negativity and the transformation of interpersonal narratives in close relationships. *J. Personality Social Psychol.* 65: 707–722.
Neisser U (1967) *Cognitive Psychology*. New York: Appleton-Century-Crofts.
Nigro G and Neisser U (1983) Point of view in personal memories. *Cogn. Psychol.* 15: 467–482.
Oishi S (2002) The experiencing and remembering of well-being: A cross-cultural analysis. *Personality Social Psychol. Bull.* 28: 1398–1406.
Ong WJ (1982) *Orality and Literacy. The Technologizing of the World*. New York: Methuen.
Parrott WG and Sabini J (1990) Mood and memory under natural conditions: Evidence for mood incongruent recall. *J. Personality Social Psychol.* 59: 321–336.
Pillemer DB (1998) *Momentous Events, Vivid Memories*. Cambridge, MA: Harvard University Press.
Polivy J and Herman CP (1983) *Breaking the Diet Habit*. New York: Basic Books.
Roberts J and Doob A (1986) Public estimates of recidivism rates: Consequences of a criminal stereotype. *Can. J. Criminol.* 28: 229–241.
Roberts JV and Doob AN (1990) News media influences on public views of sentencing. *Law Hum. Behav.* 14: 451–468.
Roediger HL I, Meade ML, and Bergman ET (2001) Social contagion of memory. *Psychon. Bull. Rev.* 8: 365–371.
Robinson MD and Clore GL (2002) Belief and feeling: Evidence for an accessibility model of emotional self-report. *Psychol. Bull.* 128: 934–960.
Rogers TB, Kuiper NA, and Kirker WS (1977) Self-reference and the encoding of personal information. *J. Personality Social Psychol.* 35: 677–688.
Rosenblatt S and Rainey R (2005) Katrina rumors: Rumors supplanted accurate information and media magnified the

problem. Rapes, violence and estimates of the dead were wrong. LA Times. www.latimes.com. Cited 9 January 2007.
Ross M (1989) Relation of implicit theories to the construction of personal histories. *Psychol. Rev.* 96: 341–357.
Ross M (2002) Temporal self-appraisal theory: Linking autobiographical memory and the self. Talk presented at American Psychological Society, New Orleans.
Ross M and Conway M (1986) Remembering one's own past: The construction of personal histories. In: Sorrentino RM and Higgins ET (eds.) *The Handbook of Motivation and Cognition: Foundations of Social Behavior*. New York: Guilford Press.
Ross M, McFarland C, Conway M, and Zanna MP (1983) Reciprocal relation between attitudes and behavior recall: Committing people to newly formed attitudes. *J. Personality Social Psychol.* 45: 257–267.
Ross M, McFarland C, and Fletcher GJ (1981) The effect of attitude on the recall of personal histories. *J. Pers. Soc. Psychol.* 40: 627–634.
Ross H, Ross M, Wilson A, and Smith M (1999) The dandelion war. In: Goldman SR, Graesser AC, and Van den Broek P (eds.) *Narrative Comprehension, Causality, and Coherence: Essays in Honor of Tom Trabasso*, pp. 253–277. Mahwah, NJ: Erlbaum.
Ross M, Spencer SJ, Lindardatos L, Lam KCH, and Perunovic M (2004) Going shopping and identifying landmarks: Does collaboration improve older people's memory? *Appl. Cogn. Psychol.* 18: 683–696.
Ross M and Wilson AE (2000) Constructing and appraising past selves. In: Schacter DL and Scarry E (eds.) *Memory, Brain, and Belief*, pp. 231–258. Cambridge, MA: Harvard University Press.
Ross M and Wilson AE (2002) It feels like yesterday: Self-esteem, valence of personal past experiences, and judgments of subjective distance. *J. Personality Social Psychol.* 82: 792–803.
Ross M and Wilson AE (2003) Autobiographical memory and conceptions of self: Getting better all the time. *Curr. Dir. Psychol. Sci.* 12: 66–69.
Ross M, Xun WQE, and Wilson AE (2002) Language and the bicultural self. *Personality Social Psychol. Bull.* 28: 1040–1050.
Sahdra B and Ross M (2007) Group identification and historical memory. *Personality Social Psychol. Bull.* 33: 384–395.
Sanitioso RB and Niedenthal PM (2006) Motivated self-perception and perceived ease in recall of autobiographical memories. *Self Ident.* 5: 73–84.
Sanitioso R, Kunda Z, and Fong GT (1990) Motivated recruitment of autobiographical memories. *J. Personality Social Psychol.* 59: 229–241.
Schlenker BR and Weigold MF (1992) Interpersonal processes involving impression regulation and management. *Annu. Rev. Psychol.* 43: 133–168.
Singer JA and Salovey P (1988) Mood and memory: Evaluating the network theory of affect. *Clin. Psychol. Rev.* 8(2): 211–251.
Singer JA and Salovey P (1993) *The Remembered Self: Emotion and Memory in Personality*. New York: Free Press.
Slovic P and Fischhoff B (1977) On the psychology of experimental surprises. *J. Exp. Psychol. Hum. Percept. Perform.* 3: 544–551.
Smith SM and Petty RE (1995) Personality moderators of mood congruency effects on cognition: The role of self-esteem and negative mood regulation. *J. Personality Social Psychol.* 68: 1092–1107.
Stillwell AM and Baumeister RF (1997) The construction of victim and perpetrator memories: Accuracy and distortion in role-based accounts. *Personality Social Psychol. Bull.* 23: 1157–1172.
Symons CS and Johnson BT (1997) The self-reference effect in memory: A meta-analysis. *Psychol. Bull.* 121: 371–394.
Thompson MS, Judd CM, and Park B (2000) The consequences of communicating social stereotypes. *J. Exp. Soc. Psychol.* 36: 567–599.
Vicente KJ and Brewer WF (1993) Reconstructive remembering of the scientific literature. *Cognition* 46: 101–128.
Vicente KJ and de Groot AD (1990) The memory recall paradigm: Setting the historical record straight. *Am. Psychol.* 45: 285–287.
Vollrath DA, Sheppard BH, Hinsz VB, and Davis JH (1989) Memory performance by decision-making groups and individuals. *Org. Behav. Hum. Decision Process.* 43: 289–300.
Walker WR, Skowronski JJ, and Thompson CP (2003) Life is pleasant and memory helps keep it that way! *Rev. Gen. Psychol.* 7: 203–210.
Wegner DM (1986) Transactive memory: A contemporary analysis of the group mind. In: Mullen B and Goethals GR (eds.) *Theories of Group Behavior*, pp. 185–208. New York: Springer-Verlag.
Wegner DM, Erber M, and Raymond P (1991) Transactive memory in close relationships. *J. Exp. Soc. Psychol.* 61: 923–929.
Weldon MS (2001) Remembering as a social process. In: Medin DL (ed.) *The Psychology of Learning and Motivation,* vol. 40, pp. 67–120. San Diego: Academic Press.
Weldon MS and Bellinger KD (1997) Collective memory: Collaborative and individual processes in remembering. *J. Exp. Psychol. Learn. Mem. Cogn.* 23: 1160–1175.
Wilson AE and Ross M (2000) The frequency of temporal-self and social comparisons in people's personal appraisals. *J. Personality Social Psychol.* 78: 928–942.
Wilson AE and Ross M (2001) From chump to champ: People's appraisals of their earlier and present selves. *J. Exp. Soc. Psychol.* 80: 572–584.
Wilson AE and Ross M (2003) The identity function of autobiographical memory: Time is on our side. *Memory* 11: 137–149.
Woike B, Mcleod S, and Goggin M (2003) Implicit and explicit motives influence accessibility to different autobiographical knowledge. *Personality Social Psychol. Bull.* 29: 1046–1055.

# 2.48 Collective Memory

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Collective memory is a representation of the past that is shared by members of a group such as a generation or nation-state. Instead of focusing on individual experience and memory, the study of collective memory examines social phenomena such as commemoration, history education, and mass media to understand how they give rise to shared accounts of the past. In some cases, the events in collective memory have occurred during the lifetime of members of the group, and in others they are from decades or centuries earlier, but in all instances the emphasis is on the social, cultural, and psychological processes that give rise to shared representations.

Instead of neutral knowledge, collective remembering typically involves beliefs – often strongly held – that are tied to identity, and hence they may evoke strong emotions when challenged. The fact that different groups can have quite different accounts of the past means that social identity and the politics of identity typically must be taken into account.

The concept of collective memory is often traced to writings of the French sociologist Halbwachs (1887–1945), who argued that remembering is shaped by participation in collective life and that there are as many accounts of the past as there are collectives (Halbwachs, 1992) (The two major works by Halbwachs in English – *On Collective Memory* (1992) and *The Collective Memory* (1980) – are compilations of French publications from the 1920s, 1930s, and early 1940s. He died in Buchenwald concentration camp shortly before the end of World War II.). In recent decades, related terms such as public memory (Bodnar, 1992) and cultural memory (Assmann, 2006; Lotman, 1990) have emerged alongside of collective memory and are now part of the memory industry (Klein, 2000) in the humanities and social sciences. A concern with these topics can be found in academic disciplines such as psychology (Pennebaker et al., 1997), anthropology (Cole, 2001), history (e.g., Novick, 1999), and sociology (e.g., Schuman and Rodgers, 2004), and it is also widely encountered in public discussions of issues such as the Holocaust and the Vietnam War.

Despite – or perhaps because of – the fact that collective memory is so widely discussed in the public sphere and academic disciplines, there is little agreement on its definition. In contrast to the study of individual memory, where some concurrence exists on basic constructs and methods, definitions of collective memory, let alone the methods for studying it, vary widely. Indeed investigators usually seem to be quite unaware of the work of others, even when they employ the same terms.

In an attempt to lay out a conceptual map for this field of inquiry, I shall use collective memory as a general term to discuss findings from a range of disciplines and theoretical traditions. Scholars such as Gedi and Elam (1996) object to this, viewing collective memory as a poor substitute for older terms such as political tradition and myth. For them, using the term is "an act of intrusion . . . forcing itself like a molten rock into an earlier formation . . . unavoidably obliterating fine distinctions" (Gedi and Elam, 1996: 30). The problem with such critiques is that they do not deal with the issue of how various strands of inquiry can be related to one another. Instead of assuming that these strands will remain isolated, the emphasis in what follows is on how they can be connected into a larger whole.

This review will be organized around sections concerned with: (1) collective memory as social framing, (2) collective memory in the social construction of groups, and (3) collective memory as semiotic distribution. These three topics are not so much competing perspectives on the same set of issues as different research traditions that have had little contact, each with its own theoretical and methodological starting point. The tradition concerned with memory as social framing focuses on how individuals' memories are shaped by social forces. Its main emphasis is on the influence of these social forces on individuals in a group, rather than the origin and nature of the groups themselves. The tradition concerned with the social construction of groups focuses on processes that create and maintain groups, and it tends to treat memory in an instrumental role in these processes. And the tradition concerned with collective memory as semiotic mediation draws on yet other disciplines to examine how language and other cultural tools mediate social and individual processes.

These three traditions do not line up neatly along disciplinary lines, nor do they constitute anything as coherent as schools of thought. They have, however, remained relatively self-contained and isolated lines of inquiry. This is due not so much to contradictions among them as to the fact that different communities of scholars, using different concepts and methods, are often unaware of the others' existence. However, the terms memory and collective memory are widely used across approaches, and for this reason these traditions of inquiry can be viewed as providing different answers to a basic question that guides this chapter: What makes collective memory collective?

All three traditions I shall outline are united in their acceptance of a psychological dimension of the larger picture, a point worth noting since this means they avoid the pitfalls of a strong version (Wertsch, 2002) that sometimes emerges in discussions of collective memory. Strong versions in one way or another assume the existence of memory in some sort of group mind, an assumption that is usually grounded in parallels between individual and collective processes. Such ideas – often in the form of unexamined assumption – have been criticized at least since Bartlett objected to positing a "more or less absolute likeness . . . between social groups and the human individual" thereby assuming that "whatever is attributed to the latter has been ascribed to the former" (Bartlett, 1932: 293).

Bartlett, who used the term social psychology quite strategically in the subtitle of his landmark monograph *Remembering*, rejected a strong version of collective memory (social memory in his terminology). He did so by stressing the difference between "memory *in* the group," which he embraced as the focus of his research, and "memory *of* the group" (Bartlett, 1932: 296, italics in the original), which he rejected as being a fundamentally misguided notion. In his view "Social direction and control of recall – memory within the group – are obvious; but a literal memory *of* the group cannot, at present at least, be demonstrated" (Bartlett, 1932: 298). As will be argued, the tradition of inquiry concerned with collective memory as semiotic distribution provides the clearest means for avoiding a strong version of collective memory, but all three traditions avoid the pitfalls of a strong version of collective memory in one way or another.

These traditions also share a preference for focusing on remembering as a process rather than memory as a static object or body of information. For reasons similar to those that motivated Bartlett to title his 1932 text *Remembering*, it is would be preferable to speak of collective remembering rather than collective memory. Using the former emphasizes the centrality of what Bartlett called the "effort after meaning." In the case of collective remembering, using the term furthermore highlights the active social and political processes involved, processes of contestation and conflict between visions of the past. But collective memory is a term that is so widely used in academic and popular discourse that any attempt to ban it would be futile. Hence, I shall use collective memory and collective remembering interchangeably in what follows.

## 2.48.1 Collective Memory as Social Framing

At least since the 1920s scholars have argued that remembering must be viewed as a socially framed or situated activity. When Halbwachs said that there are as many memories as groups, he often had such ideas in mind, a point that is reflected in his assertion that "it is individuals as group members who remember" (Halbwach, 1980: 48), and as already noted, Bartlett made similar claims. Both of these founders of memory studies took it as a given that individuals – but socially situated individuals – remember. As Olick (1999) has noted, Halbwachs sometimes appeared to be ambivalent on this issue, and at some points he even seemed to accept a strong version of collective memory (Wertsch, 2002). However, many passages in his writings are quite similar to what can be found in Bartlett.

The social framing of memory has continued to be an important thread of research in psychology and sociology, even shaping the study of forms of remembering that appear to be prototypically individual. This can be seen in the research on flashbulb memory. Since being introduced by Brown and Kulik

(1977), this phenomenon has been the object of widespread interest both in psychology and the broader public. Neisser (1982) defines it as "a subjectively compelling recollection of an occasion when we heard an important piece of news" (Neisser, 1982: 43). It appears to be intensely personal since the memory involved focuses on the individual's own experience of the event rather than the event itself.

Some flashbulb memories are about specific events experienced by individuals and derive from "the sundry private shocks in each person's life" (Brown and Kulik, 1977: 75) such as hearing about the death of a family member. However, most cases examined in the literature concern events that are jointly experienced, and it is in this connection that they have a collective dimension. The assassination of President John F. Kennedy in 1963 provides the classic example of this. Virtually everyone in the United States above early childhood at the time has a vivid and subjectively compelling recollection of where she was and how she heard about it. Along with other events such as the assassination of Martin Luther King, Jr., the 1986 Challenger shuttle explosion, and the terrorist attacks of September 11, 2001, such instances of flashbulb memory are widely shared in the United States.

From the very outset of flashbulb memory studies there have been attempts to address its collective dimensions. Brown and Kulik, for example, reported group differences between African Americans and White Americans in flashbulb memories for the assassinations of civil rights leaders. A tendency to view flashbulb memories as individual phenomena runs throughout the literature, however, largely because the research has focused on individuals' personal impressions and reactions rather than attention to the shared historical event. As Brown and Kulik noted, flashbulb memory is above all "memory for the *circumstances* in which one first heard the news" (Brown and Kulik, 1977: 95), vivid images of precisely where we were, what we were doing, who told us the news, and so forth, instead of memory for the historical event itself.

In more recent research, additional claims about the collective framing of flashbulb memories have been pursued. For example, in two studies of flashbulb memories for earthquakes (Er, 2003; Neisser et al., 1996), investigators found differences between groups of subjects who experienced the event directly and those who found out about it indirectly through media reports. A more elaborated account of group differences having to do with social identity can be found in a study by Berntsen and Thomsen (2005). Concerned with "the accuracy and clarity of [flashbulb memories] as a function of emotional and social factors" (Berntsen and Thomsen, 2005: 242), they examined Danes' memories for the German invasion of their country in 1940 and its liberation in 1945. Specifically, they examined differences between the memory of Danes who had ties to the resistance movement in World War II and those who did not and found that those in the first group had more vivid and accurate memories than subjects who did not.

In another study, Bohn and Berntsen (2007) examined additional aspects of the impact of group membership on flashbulb memory. In this case, the object of memory was the fall of the Berlin Wall in 1989. Germans who viewed the event either negatively or positively participated in the study. Those in the positive group rated their memories higher in terms of reliving and sensory imagery, but their memories were actually less accurate than participants in the negative group, something that Bohn and Berntsen attribute to a more "detail-oriented, bottom-up processing strategy related to negative affect" (Bohn and Bernsten, 2007: 571) for the negative group. They also note that differences in accuracy may be due to increased levels of discussing and rehearsing the event by the positive group, practices typically grounded in schema-based organization that derives from narrative retelling.

In sum, although flashbulb memories need not be about events experienced by a group, most of the cases studied to date are in fact of this sort. This has led some investigators to be concerned with how memory processes in one group may differ from those in another. Findings indicate that such differences can be complex, involving more than the amount of information recalled. This is part of the larger set of issues originally raised by Bartlett about the social framing of memory, issues that occasionally make it into psychological studies. While interesting, these issues "have not been systematically pursued" (Roediger, 2000: 155) to date.

## 2.48.2 Collective Memory in the Social Construction of Groups

In the view of Olick (1999), the sort of social framing discussed in the previous section is concerned with collect*ed*, as opposed to collect*ive*, memory since it amounts to "the aggregation of socially framed individual memories" (Olick, 1999: 333). In such cases, the social dimension enters the picture as a kind of independent variable having to do with objective facts about group membership. In some instances, this group membership is a matter of culturally salient categories such as race or political affiliation, and in others it amounts to little more than happening to be part of a group that experienced a major event together. From this perspective, group membership is viewed primarily as a predictor of individual memory performance.

In contrast, several investigators in sociology and psychology have outlined alternative proposals concerned with what Olick considers to be genuinely collective memory. A hallmark of this approach is that collective remembering involves social facts (Durkheim, 1982) and processes that cannot be reduced to individual psychological phenomena. As a student of Durkheim, whose ideas have done much to shape contemporary discussions in sociology, much of what Halbwachs (1980, 1992) argued fell under this heading. In more recent years, this point has sometimes been framed as a rejection of methodological individualism (Lukes, 1977). In the cases I shall review, however, the difference is more one of interest and emphasis than simple opposition to studies in psychology and other disciplines that focus on the individual.

One important strand of research concerned with what Olick views as genuinely collective memory concerns the social formation of groups. From this perspective the group is a product, rather than a prerequisite of shared memory. This is a line of reasoning that is often traced to the writings of the sociologist Mannheim, especially his essay "The problem of generations" (Mannheim, 1951). There he argued for the need to follow a romantic-historical, as opposed to a positivist, approach to group membership. Specifically, he argued for the need to view a generation as subjectively constructed and defined rather than a cohort determined by objective dates. From this perspective, generations are "mental and spiritual units" (Mannheim, 1951: 289) that come into being because people share historical experience and memories.

Schuman and his colleagues have explored several implications of this line of reasoning (e.g., Schuman et al., 1997; Schuman and Scott, 1989). Instead of being a reflection of group membership, these investigators view collective memory as playing a role in the construction of the mental and spiritual units of generations. The emphasis is on how a generation comes into being as its political outlook is shaped by the events its members experience, especially during the critical period of young adulthood. Thus the greatest generation (Brokaw, 2001) was fundamentally shaped by events it experienced in World War II, the Vietnam generation is haunted (McPherson, 2002) by events it experienced in the 1960s and 1970s, and so forth.

An essential part of Schuman's argument is that "adolescence and early adulthood are a stage of life uniquely open to gaining knowledge about the larger world" (Schuman et al., 1997: 47). For example, Schuman et al. (1997) conducted a survey about knowledge of past events among Americans between the ages of 18 and 80 and documented that this knowledge is dependent on the point in the life course when an event is experienced. Their results generally support the claim that knowledge for events encountered in young adulthood tends to be more extensive than for events experienced before or after this critical period.

For example, Americans who were in their early twenties when the Tet Offensive of the Vietnam War occurred demonstrated greater knowledge about it a quarter century later than both younger and older people. The curvilinear pattern of knowledge involved in this case also emerged for other events such as the Holocaust and Watergate (Schuman et al., 1997). In a few instances, Schuman et al. did not find the results they predicted, something that serves as a reminder that generations are subjectively defined cohorts rather than objective periods. For example, Schuman et al. (1997) failed to find distinctive generational effects for some aspects of the Watergate scandal, namely, John Dean's role in it, and they interpreted this to "indicate that a purely mechanical approach to cohort effects on knowledge is inadequate" (Schuman et al., 1997: 74). What may be required for events to be salient for collective memory is that they are taken to be what Pennebaker and Banasik (1997) term important turning points for American self-views.

The appearance of the term knowledge throughout these discussions raises a question about why it, rather than the term memory should be invoked. In order to make the case that memory is indeed involved, one must recognize that two functionally differentiated types of knowledge are at issue in such discussions. On the one hand, there is knowledge that may be widely shared but has little relevance to identity or self-views. As reflected in the title *1066 and All That* (Sellar and Yeatman, 1931), much of what people might have been taught about the past is not taken to be particularly relevant to their contemporary concerns.

In contrast, other aspects of knowledge about the past are central to understanding and defining who we are. Just as stories we live by (McAdams, 1993) are essential means for personal identity, certain narratives play an essential role in forming collectives such as nation-states. In these latter cases, it is not simply knowledge about the past that is involved; it is knowledge that is crucial to understanding and defining identity and creating self-views. In this connection, Zerubavel (2003) notes, "acquiring a group's memories and thereby identifying with its collective past is part of the process of acquiring any social identity, and familiarizing members with that past is a major part of communities' efforts to assimilate them" (Zerubavel, 2003: 3).

Assmann (1997) has discussed these issues under the heading of a distinction between history and memory. For him, the latter is vitally tied to contemporary discussions of identity. In its case, "The past is not simply 'received' by the present. The present is 'haunted' by the past and the past is modeled, invented, reinvented, and reconstructed by the present" (Assmann, 1997: 9).

In this respect, there are several points of possible contact between collective memory research and psychological studies of individual memory. For example, the centrality of identity in collective remembering suggests interesting parallels with the notions of a self-memory system as outlined by Conway and Williams (*See* Chapter 2.46). It also raises issues of how collective memory is related to constructs from psychology such as semantic and episodic memory. In many instances of collective remembering, the focus is clearly on an episode from the past, hence suggesting parallels with episodic memory. However, closer analysis usually reveals that some sort of more general category or abstract schema seems to be involved, suggesting parallels with semantic memory. As Balota and Coane (*See* Chapter 2.28) point out, however, the distinction between semantic and episodic memory is difficult to maintain in discussions of psychological processes, and trying to examine the psychological dimensions of collective remembering may further complicate this. It is also possible that research on grounding semantics in perceptual motor systems (*See* Chapter 2.28) may eventually provide insight into the psychological dimensions of collective remembering.

The major point to be kept in mind when engaging in such discussions is that knowledge about the past counts as collective remembering when it becomes crucial to the project of constructing group identity. A usable past is almost always crucial to such projects, and for this reason people become very attached to certain historical narratives, even going to far as to invent, reinvent, or reconstruct them to meet the needs of the present. Among other things, this points to the need to understand the emotional dimensions of collective remembering, perhaps harnessing some of the ideas of Barsalou (1999) about how knowledge is stored in perceptual symbol systems.

Claims about assimilating people into a mnemonic community (Zerubavel, 1997) beg the question of how this is done and when in the lifespan the effort might be most effective, and it is here that other fruitful connections among various traditions of memory studies can be forged. In this connection, there are obvious ties to be made between sociological studies by researchers such as Schuman et al. on critical periods in the formation of a generation and the notion of a reminiscence bump outlined in psychological studies of memory and the fact that the autobiographical memories retrieved are disproportionately from ages 15–25. Rubin et al. (1986) proposed this notion when analyzing the life span retrieval curve that has been observed in individuals above the age of 35. They collected evidence for this phenomenon by employing techniques such as presenting subjects with a word and asking them to provide the first autobiographical memory that comes to mind.

Rubin et al. (1998) report that such procedures repeatedly yield greater numbers of memories dating between the ages of 10 and 30 than for earlier or later periods in subjects' lives. Conway and Pleydall-Pearce (2000) similarly conclude that "the knowledge acquired during the reminiscence period is highly accessible and more accessible than knowledge outside this period" (Conway and Pleydall-Pearce, 2000: 19). Rubin et al. (1998) consider several explanations for why this is so and accept an account based on the novelty of experience and its effect on memory.

Building on the ideas of Erikson about identity development and on further empirical studies, Conway and Pleydell-Pearce provide another interpretation, namely that "the reminiscence bump reflects preferential retention of events from a period of consolidation of the self" (Conway and Pleydall-Pearce, 2000: 20). This involves forming long-term allegiances and friendships, developing a life story schema, and generating a life narrative. To the extent that these processes take place in the context of major historical events such as war, economic depression, or assassinations, one can expect events to have a formative role in individuals' and generations' political outlook.

Combining ideas about the reminiscence bump with the analysis of how memory functions in the social formation of collectives points to the importance that young adults' experiences have on the political outlook of generations. This is a point that has been recognized by those who wish to control this experience. In this connection Mannheim noted, "it may sometimes happen that a feeling for the unity of a generation is consciously developed into a basis for the formation of concrete groups, as in the case of the modern German Youth Movement" (Mannheim, 1951: 288).

In general, studies of memory in the social construction of groups focus on how effective such memory is in the formation of collectives. This orientation has led sociologists such as Fine (2001) to write about how reputational entrepreneurs try to shape the way that deeds are remembered as part of an effort to enhance group pride and membership. This emphasis contrasts with research on socially framed memory, which tends to be more concerned with accuracy or inaccuracy. This does not mean that those concerned with memory in the social construction of groups have no interest in accuracy, but their primary emphasis remains on which memory or which aspect of memory will be most effective in creating group identity. For example, Novick (1999) has argued that collective memory for the Holocaust in America is to a large degree motivated by a desire to reproduce Jewish identity, but at the same time there obviously remains a deep commitment to accuracy in representing the past.

Renan (1990) recognized this in his famous lecture (delivered at the Sorbonne in 1882) 'What is a nation?' where he noted that collective memory, whose core role is to enhance national identity, stands in contrast to analytic studies of history, which aspire to be maximally accurate and complete. As suggested by Assmann's assertion that the present reconstructs the past in memory, Renan believed that "Forgetting, I would even go so far as to say historical error, is a crucial factor in the creation of a nation, which is why progress in historical studies often constitutes a danger for [the principle of] nationality" (Renan, 1990: 11). From this perspective, elites such as state authorities constantly try to shape what Renan called the daily plebiscite on national identity, and collective memory is one of their main tools for doing this.

Perhaps the most forceful formulation of this point can be found in *Nineteen Eighty-Four*, where George Orwell warned, "Who controls the past controls the future; who controls the present controls the past" (Orwell, 1949: 204). While seldom stated in such stark terms, all modern states make an effort to create and maintain collective remembering that will enhance identity and loyalty. This is crucial for what the anthropologist Anderson (1991) has termed imagined communities and what the political theorist Smith (2003) calls people making. Both authors are concerned with the massive institutional resources devoted to constructing group identity. Huntington (2004) takes Anderson's notion a step further in arguing that a nation is "more specifically a remembered community, a community with an imagined history, and it is defined by its historical memory of itself" (Huntington, 2004: 115).

An essential feature of remembered communities is that more than one account of the past competes for the role of being the officially recognized memory. Bodnar (1992) has addressed these issues from the perspective of what he formulates as public memory. This involves a dialectic between the official culture promulgated by state authorities and other elites, on the one hand, and the vernacular culture of everyday life, especially of the nonelites, on the other. For example, in constructing war memorials, official culture celebrates the triumphal vision of the unified nation, whereas vernacular culture often seeks to find a way to interpret events from a perspective of the private pain experienced by those who lost a friend or family member. Bodnar notes that by including the names of individual Americans on the monument, the Vietnam War Memorial in Washington, DC, breaks with earlier practices of celebrating the official cultural view while downplaying the vernacular perspective. In this case, vernacular cultural practices that commemorate private loss and pain have become as much a part of public memory as the official culture perspective that emphasizes the nation as a whole.

Bodnar has explored the dialectic between public and vernacular culture in many other settings as well. For example, he harnesses this conceptual opposition to provide insight into why groups highlight their local and ethnic identities while participating in July Fourth parades that celebrate the unifying vision of the United States. Such analyses address a crucial issue of collective memory in the social formation of groups. Namely, they provide insight into how competing accounts of the past engage in an ongoing debate, thereby making collective remembering into something like an arena of ongoing contestation rather than a set body of received knowledge. Orwell's dictum reminds us that state authorities and other elites have a natural tendency to present the past as such received knowledge, but this is always open to challenge through processes such as those Bodnar outlines under the heading of vernacular culture.

## 2.48.3 Collective Memory as Semiotic Distribution

The third tradition of collective memory studies I shall consider provides yet another answer to the question: What makes collective memory collective? The starting point in this case is the notion of a distributed, as opposed to a strong, version of collective remembering (Wertsch, 2002). In this view, remembering is taken to be distributed in the sense that along with active individuals, it requires cultural tools such as written symbols or mnemotechnics (Yates, 1966). And what makes it collective is that members of a group share the same cultural tool kit (Bruner, 1990). All this does not mean that the tools somehow remember on their own, a claim that would amount to instrumental reductionism, but it does emphasize how extensively humans rely on semiotic means provided by their cultural, historical, and institutional contexts.

As an example of distributed memory at the individual level, consider the analysis of Hutchins (1995) of how a cockpit remembers its speed. By seeming to give cognitive instruments their own agency ("a *cockpit* remembers"), Hutchins emphasizes the importance that they can play in cognition and memory. In this particular case, he examines how a pilot can set and then check with recording devices in an airplane cockpit to keep track of information, and in the process he argues that any assignment of memory to the individual or to instrumentation alone is misguided. Instead, both human agents and the cultural tools they employ must be viewed as integral components of a memory system.

In most studies of semiotically distributed remembering, the emphasis is on how written or spoken language serves as a cultural tool. A major historical transformation in this regard came with what Donald (1991) calls the third transition in human cognitive evolution, one characterized by "the emergence of visual symbolism and external memory as major factors in cognitive architecture" (Donald, 1991: 17). The primary engine of change in this case was not within the individual, but external symbolic storage such as written texts and financial records. Donald stresses that these new forms of external symbolic storage have a transformational impact on psychological and neurological processes; they "impose search strategies, new storage strategies, new memory access routes, new options in both the control of an analysis of one's own thinking" (Donald, 1991: 19). As a contemporary example in the early twenty-first century consider the new skills and strategies that have emerged with the appearance of Google and other search engines on the Internet.

Approaching memory from the perspective of semiotic distribution raises the question of how the use of different linguistic tools gives rise to different forms of memory. Instead of being viewed as simply facilitating existing forms of memory, leaving them otherwise unchanged, such tools are assumed to shape remembering in fundamental ways. A further twist to this line of reasoning stems from the fact that the primary function of language is not to serve as a cognitive or memory tool. Instead, its primary function is communication, and the role it takes on as a tool for remembering is derivative in an important sense. Authors such as Middleton and Brown (2005) have made this point in their study of collective memory. There they argue that the language used to recount the past may depend as much on the need to be convincing or on other communicative goals as it depends on any inclination to be accurate.

A major focus in the study of how language affects remembering is narrative. Researchers from a variety of disciplines have found it useful to make a basic distinction between forms of memory that are mediated by narratives and those that are not. In the case of individual memory, for example, Pillemer (1998) distinguishes between imagistic and narrative forms of "personal event memories" (Pillemer, 1998: 7). Pillemer and White (1989) argue that imagistic memory is "present from birth and operational throughout life . . . The memories are expressed through images, behaviors, or emotions" (Pillemer and White, 1989: 326). In contrast, the narrative memory system "emerges during the preschool years . . . Event representations entering the higher-order system are actively thought about or mentally processed and thus are encoded in narrative form. . . . Memories in the higher-order system can be accessed and recounted in response to social demands" (Pillemer and White, 1989: 326).

Pillemer formulated this distinction in order to analyze developmental issues such as childhood amnesia, where the concern is how imagistic memory is eventually supplemented by remembering mediated by narratives. This does not mean, however, that the former is thought to disappear. Instead, imagistic memory is assumed to continue to exist in adulthood, a claim reflected in Brown and Kulik's account of flashbulb memory, which they speculated "is not a narrative and not even in verbal form, but represented in other, perhaps imaginal ways" (Brown and Kulik, 1977: 85).

Other discussions in the research literature on individual memory focus on distinctions between implicit and explicit memory (Roediger, 1990; Schacter, 1996) or unaware and aware uses of memory (Jacoby, 1988). An essential property of implicit memory is that it is nonconscious (Tulving and Schacter, 1990), which contrasts with explicit memory involving episodic form, which, in turn, is usually taken to involve narrative. Such narrative form is taken to be essential in organizing information and making it available to consciousness. According to Schacter (1994), "a key function of the episodic system is to bind together perceptual with other kinds of information (e.g., semantic, contextual) and thereby allow subsequent recall or recognition of multiattribute events" (Schacter, 1994: 257).

The relationship between imagistic and narrative forms of remembering is often formulated in terms of translation. For example, Pillemer provides an alternative account of repressed memories in terms of a failure of translation (Pillemer, 1998: 133). From this perspective, it is a failure to translate imagistic forms of remembering into narratives that gives rise to what others have called repression. And in the quite distinct realm of historical research, the semiotician Lotman (1990) made an analogous claim.

> Even when the historian is an observer of the events described (examples of this rare occurrence are Herodotus and Julius Caesar), the observations still have to be mentally transformed into a verbal text, since the historian writes not of what was seen but a digest of what was seen in narrative form . . . The transformation of an event into a text involves, first, narrating it in the system of a particular language, i.e., subjecting it to a previously given structural organization. (Lotman, 1990: 221)

From a psychological perspective, one of the important implications of such translation is that it makes possible reflection and control, processes that take on particular importance when dealing with traumatic experience. In a discussion of overcoming traumatic events, for example, Harber and Pennebaker (1992) report that "victims must consciously confront the memories and emotions associated with their traumatic ordeals. This confrontation is best accomplished by translating the chaotic swirl of traumatic ideation and feelings into coherent language" (Haber and Pennebaker, 1992: 360).

As in the case of research on memory in individuals, narrative form provides the basis for distinguishing between different types of collective remembering. The Egyptologist and historian Assmann (2006), for example, distinguishes between cultural memory, under which he includes nonnarrative forms such as foods and landscapes, on the one hand, and national narratives, which impose "a coherent ordering of events along a strict narrative line serving as an intellectual and emotional backbone of national identity" (Assmann, 2006: 21), on the other. This latter form of representation brings along with it tendencies toward being "mono-perspective, ethnocentric, and narcissistic" (Assmann, 2006: 21). As is the case for narratives in general, national narratives are assumed to "grasp together" (Ricouer, 1985: 44) events, characters, and motives into a coherent representation of the past, much in the way that Schacter says episodic memory binds together information.

Research on individual and collective remembering is distinguished, however, by assumptions about the source of the narratives involved. Psychological studies of episodic memory typically assume that narrative organization is generated by the individual. There is little doubt that narrative cognition (Feldman and Kalmar, 1996) is widely used in the effort after meaning that shapes collective remembering as well, but it is typically viewed as involving narrative tools that are provided by the sociocultural context in which individuals function. Again, from this perspective, what makes collective memory collective is the fact these narrative tools are shared across the members of a group.

In this account, collective remembering harnesses existing narratives in the "tool kit" that is "already 'there,' deeply entrenched in culture and language" (Bruner, 1990: 11) to make sense of the past. Of course active agents are always involved and every use of these tools is unique, even creative in some way, but this performance is viewed as harnessing items in what MacIntyre (1984) calls a society's stock of stories. One implication is that Orwell's dictum could be restated as: He who controls the present, controls 'narratives about' the past. He who controls 'narratives about' the past, controls the future.

Heated debates and memory wars provide striking illustrations of these issues. Such debates occur over commemorative monuments, holidays, museums, and history teaching. In the United States, these debates have been over how to represent the atomic bombing of Hiroshima and Nagasaki (Linenthal and Engelhardt, 1996); in India they reflect an ongoing struggle between secularists and religious parties over what narrative would be appropriate for textbooks (Thapar, 2003); and in China they may touch on Japan's collective amnesia (Chang, 1997) about the rape of Nanking in the 1930s.

In reality these concerns do not surface only in history wars; they are part of everyday life in the modern world. Forces of the everyday, unnoticed practices of banal nationalism (Billig, 1995) and the national narratives that are a part of it exist everywhere, and they sometimes come into sharp focus in encounters between collective memory communities. As an example of this, consider an interchange reported by Wertsch (2002) between an American adult and a Russian high school student (Sasha) in the late 1990s. During a visit to a history class in a high school in Moscow, the American adult posed a question to the class about the role of Soviet allies in World War II. The first reaction by Sasha and his classmates suggested that they viewed this as a sort of pedagogical – if not pedantic question to which everyone knows the answer. After making it clear that he took the exercise to be just that, Sasha replied:

> The United States made a lot of money from selling arms and other things to countries during the early years of the war, but it did not really contribute as an ally. In fact, along with Great Britain it refused to open a second front in 1942 and again in 1943. It was only after the U.S. and Britain began to think that the Soviet Union might win the war by itself and dominate post-war Europe that they became concerned enough to enter the war in earnest by opening a second front in 1944. (Wertsch, 2002: 4)

This account differs strikingly from what one finds in the United States – as well as many other places in the world. Indeed, Sasha's narrative might appear to American observers as an effort to be provocative, but in fact he produced it at time of relatively positive feelings toward the United States, and he and many, if not most Russians take what he said simply as a straightforward depiction of what occurred. Furthermore, like many Russians, he would undoubtedly have remained committed to this narrative in the face of what appears to others to be contradictory evidence.

An important fact about Sasha's account is that it is very unlikely that he arrived at it through independent research or the consideration of a range of alternatives. Instead, like most of us in such situations, he employed a standard narrative from the cultural tool kit provided by the textual tradition into which he had been socialized.

In such cases, speakers often fail to appreciate the power of narrative tools to shape what they are saying. Sasha, for example, demonstrated little awareness of the existence of the standard narrative he was using, let alone of how it might be contested. He said nothing like: "What we read in our history books is..." or "I saw in a movie that ..." or "I know that the U.S. has another account, but we believe ..." Instead, he presented his account as simply a description of what really happened, something that reveals a fundamental property of narratives in recounting the past: their transparency (Wertsch, 2002). It was as if he were looking through this narrative tool just as he would look through a clear pane of glass without recognizing that it separated him from the events being reported.

This anecdote about Sasha reflects a larger picture of Russian collective memory and how the narrative tools it employs differs from what can be found elsewhere. Consider, for example, an exercise I often conduct with American undergraduates in which they are to list the most important events of World War II. The procedure consistently yields the following most frequently mentioned items:

Attack on Pearl Harbor (December 7, 1941)
Battle of Midway (June 1942)
D-Day (June 6, 1944)
Battle of the Bulge (winter 1944–45)
Holocaust (throughout the war)
Atomic bombing of Hiroshima and Nagasaki (August 1945)

Results from surveys of Russians in Moscow as well as Novosibirsk in the late 1990s (Wertsch, 2002) provided a quite different list of most frequently chosen items:

German attack on USSR (June 22, 1941)
Battle of Moscow (winter 1941–42)
Battle of Stalingrad (winter 1942–43)
Battle of the Kursk salient (summer 1943)
Siege of Leningrad (1942–44)
Final Battle of Berlin (1945)

A striking fact about these two lists and the narratives they suggest is that there is no overlap. Many Russians know about the events on the American list, but they do not view them as central to the narrative of the war. For example, Russians are quite familiar with the episode called opening the second front in June of 1944. For them, this refers to something that was not only a second, but clearly a secondary front (there is no word for D-Day in Russian), and it is not considered a major event, let alone a turning point in World War II. Conversely, American students often know little about events typically listed by Russians. For example, the largest tank battle in history at the Kursk salient is something that has no resonance in American collective memory, but it is taken to be one of the turning points in the Russian narrative of World War II. Furthermore, it is at the center of scholarly accounts, including those of Western historians such as Overy (1997).

In contrast to such national differences in collective remembering, recent findings by Liu and colleagues (Liu et al., 2005) suggest some similarities. They report a high level of consensus when they asked subjects in six Western and six Asian countries to list the most important events and figures in history for the past 1000 years. The subjects across the groups shared a tendency to focus on the recent past and to include at the top of their list political events and wars, especially World War II. Such findings about similarities across groups led the authors of this study to conclude that "the degree of cross-cultural consensus suggests that hybridity across Eastern and Western cultures in the representation of knowledge may be underestimated" (Liu et al., 2005: 1).

In the end, these results may not contradict the picture of difference between mnemonic communities outlined in the Russian-American case because the nature of the events and the time frames involved are so different. It will only be with much more research of the sort conducted by Liu and colleagues that we will begin to gain clarity on these issues.

In the study of how narratives shape collective remembering, a useful distinction between specific narratives and schematic narrative templates (Wertsch, 2002) can be made. Specific narratives include information about concrete events, actors, times, and places. Sasha's account of the role of the Allies in World War II is an example. Schematic narrative templates, in contrast, are more abstract in nature. They are schematic in the sense outlined by Bartlett in his account of the schemas that shape remembering or by the folklorist Propp (1968) in his analysis of abstract functions in folktales. They are narrative in the sense that they are organized around basic narrative principles such as those outlined by Bruner (1990) and Ricouer (1985). And they are templates in the sense that they involve a generalized form from which several copies (i.e., specific narratives) can be generated.

Wertsch (2002) has outlined a basic Triumph over Alien Forces schematic narrative template that is often employed by Russians when talking about several episodes from their past. This is a general narrative template that is employed by people other than Russians, to be sure, but it plays a particularly important role as a national narrative in their case. Specific narratives that fit this pattern for Russians include accounts of the Mongol invasion of the thirteenth century, the Swedish invasion of Charles XII in the eighteenth century, the Napoleonic invasion of the early nineteenth century, the German attack in World War II, and even the reign of communism in the twentieth century.

The Triumph over Alien Forces schematic narrative template can be summarized as:

1. Russia is peaceful and not interfering with others.
2. Russia is viciously and wantonly attacked without provocation.
3. Russia almost loses everything in total defeat.
4. Through heroism and exceptionalism, and against all odds, Russia triumphs.

Emphasizing the importance of this basic narrative template in shaping Russians' interpretation of the past does not suggest that this interpretation is without foundation. Russia clearly has been the victim of numerous attacks in its history, and its people have undergone great suffering. But the effort after meaning in this case is shaped by the particularly Russian way the events are emplotted and contrasts with other interpretations. In particular, it has to do with how the meaning of actions and the motivation of those who carry them out are interpreted. For example, Estonians have long held that some of the actions that Russians interpret through the lens of the Triumph over Alien Forces are better understood in terms of Russia's longstanding, aggressive imperialism (Tulviste and Wertsch, 1994).

Partly because they are even more transparent than specific narratives, schematic narrative templates are often not recognized, let alone subject to reflection, criticism, and change. Evidence of their conservative nature can be found in the transition from the Soviet to post-Soviet official histories. On the surface, changes in the official collective memory of World War II found in textbooks are striking. Many of the things routinely included in post-Soviet Russian textbooks in 2005 would have landed people in prison had they written them in the Soviet Union of 1970. For example, the Communist Party was routinely feted as the moving force of history in Soviet accounts, but post-Soviet history textbooks, as well as the popular press, stress that it was the masses of Russian people, not the party, that won World War II. Indeed, some of these post-Soviet accounts go out of their way to say it was 'despite' the party and only through the heroism of the Russian people that the country won the war (Wertsch, 2002).

Another form of evidence that points to the conservative nature of this narrative template in Russian national consciousness can be found in references to Hitler as a second Napoleon. This formulation has remained constant across the radical changes in Russian accounts, and of course it also provides a reminder that the narrative tools used by one collective can be quite distinct from those used in other places. Whereas this is a familiar and widely repeated expression for Russians, it is not something that most Americans would have heard repeatedly as they grew up.

A great deal remains to be studied when it comes to understanding the degree to which collective remembering does or does not change. The line of argument developed by Wertsch (2002) suggests that specific narratives may change fairly quickly, but at the level of schematic narrative templates, there is a high level of conservatism and resistance to change.

Schuman et al. (2005) have recently presented a more elaborated picture of this issue. They examined Americans' account of Columbus over the past few decades and draw an important distinction between what happens with elite revisionists, on the one hand, and popular beliefs, on the other. They report that elite culture's attempt to revise the narrative about this figure has had an impact on what is presented in forums such as textbooks, but it has not had the impact on popular beliefs that one might expect. The endurance of Columbus's reputation and the "inertia of tradition" (Schuman et al., 2005: 3) can be understood only by differentiating elite and popular beliefs and tracing their dynamics.

## 2.48.4 Conclusion

The three traditions of inquiry on collective memory that I have outlined provide different visions of what makes collective memory collective. In many cases, however, differences stem more from disciplinary isolation rather than conceptual contradiction. Little citation of literature across the traditions occurs, and in many cases they do not even seem to know of the others' existence.

The study of the social framing of collective remembering has been conducted largely by psychologists and is viewed by sociologists such as Olick (1999) as being such a distinct approach that it should be labeled collected rather than collective memory. The concern with collective memory in the construction of social groups has surfaced largely in sociology and political science and shows only occasional signs of contact with the psychological study of memory. And studies of collective memory as semiotic distribution have been conducted primarily in disciplines such as history, semiotics, and anthropology, often with little benefit from the findings of the other two traditions.

Despite the dearth of contact among these approaches, there are several obvious points of contact to be made in building a more comprehensive picture of collective memory. For example, obvious complementarities exist between sociological studies of the role of memory in the formation of generations and psychological studies of the reminiscence bump. Other points of contact may have even more potential. For example, claims about the role of memory in the social formation of groups often imply notions of narrative tools, and for this reason, statements about remembered communities and people-making are as much about national narratives as about political processes.

It remains useful at this point, however, to recognize the differences among traditions of inquiry in the field of collective memory studies since this suggests a conceptual map of ideas and methods. In the end, the justification for such a map will be its ability to generate new ideas and insights into collective memory phenomena that are widely noted, but little understood. The field is rich enough that it will require a diverse set of constructs and methods to address the issues. One of the key issues that will undoubtedly continue to shape the discussion, however, will be how these ideas and methods fit together into some sort of integrated whole.

## References

Anderson B (1991) *Imagined Communities: Reflections on the Origin and Spread of Nationalism*. London: Verso.

Assmann J (1997) *Moses the Egyptian: The Memory of Egypt in Western Monotheism*. Cambridge, MA: Harvard University Press.

Assmann J (2006) Cultural memories and national narratives: With some relation to the case of Georgia. White paper report prepared for the Georgian Ministry of Education.

Bakhtin MM (1986) The problem of the text in linguistics, philology, and the human sciences: An experiment in philosophical analysis. In: Emerson C and Holquist M (eds.) *Speech Genres and Other Late Essays*, pp. 103–131, McGee VW (trans.). Austin: University of Texas Press.

Balakian P (2003) *The Burning Tigris: The Armenian Genocide and America's Response*. New York: Harper Collins.

Barsalou LW (1999) Perceptual symbol systems. *Behav. Brain Sci.* 22: 577–609.

Bartlett FC (1932) *Remembering: A Study in Experimental and Social Psychology*. Cambridge: Cambridge University Press.

Berntsen D and Thomsen DK (2005) Personal memories for remote historical events: Accuracy and clarity of flashbulb memories related to World War II. *J. Exp. Psychol. Gen.* 134: 242–257.

Billig M (1995) *Banal Nationalism*. London: Sage.

Bodnar J (1992) *Remaking America: Public Memory, Commemoration, and Patriotism in the Twentieth Century*. Princeton: Princeton University Press.

Bohn A and Berntsen D (2007) Pleasantness bias in flashbulb memories: Positive and negative flashbulb memories of the fall of the Berlin wall among East and West Germans. *Mem. Cogn.* 35(3): 565–577.

Brokaw T (2001) *The Greatest Generation*. New York: Random House.

Brown R and Kulik J (1977) Flashbulb memories. *Cognition* 5: 73–99.

Bruner J (1990) *Acts of Meaning*. Cambridge, MA: Harvard University Press.

Chang I (1997) *The Rape of Nanking: The Forgotten Holocaust of World War II*. New York: Basic Books.

Cole J (2001) *Forget Colonialism? Sacrifice and the Art of Memory in Madagascar*. Berkeley: University of California Press.

Conway MA and Pleydell-Pearce CW (2000) The construction of autobiographical memories in the self-memory system. *Psychol. Rev.* V107(2): 1–28.

Donald M (1991) *Origins of the Modern Mind: Three Stages in the Evolution of Culture and Cognition*. Cambridge, MA: Harvard University Press.

Durkheim E (1982) *The Rules of Sociological Method,* Lukes S (ed.), Halls WD (trans.). New York: Free Press.

Er N (2003) A new flashbulb memory model applied to the Marmara earthquake. *App. Cogn. Psychol.* 17: 503–517.

Feldman CF and Kalmar DA (1996) Some educational implications of genre-based mental models: The interpretive cognition of text understanding. In: Olson DR and Torrance N (eds.) *The Handbook of Education and Human Development: New Models of Learning, Teaching and Schooling*, pp. 434–460. Oxford: Blackwell.

Fine GA (2001) *Difficult Reputations: Collective Memory of the Evil, Inept, and Controversial*. Chicago: University of Chicago Press.

Gedi N and Elam Y (1996) Collective memory – What is it? *Hist. Mem.* 8(2): 30–50.

Halbwachs M (1980) *The Collective Memory*, Didder F Jr and Yazdi Ditter V (trans.) New York: Harper and Row.

Halbwachs M (1992) *On Collective Memory,* Coser LA (ed., trans.). Chicago: University of Chicago Press.

Harber KD and Pennebaker JW (1992) Overcoming traumatic memories. In: Christianson S-A (ed.) *The Handbook of Emotion and Memory: Research and Theory*, pp. 359–387. Hillsdale NJ: Erlbaum.

Huntington S (2004) *Who Are We? The Challenges to America's National Identity*. New York: Simon and Schuster.

Hutchins E (1995) How a cockpit remembers its speed. *Cogn. Sci* 19: 265–288.

Jacoby LL (1988) Memory observed and memory unobserved. In: Neisser U and Winograd U (eds.) *Remembering Reconsidered: Ecological and Traditional Approaches in the Study of Memory*, pp. 145–177. New York: Cambridge University Press.

Klein KL (2000) On the emergence of memory in historical discourse. *Representations* 69: 127–150.

Linenthal ET and Engelhardt T (1996) *History Wars: The Enola Gay and Other Battles for the American Past*. New York: Metropolitan Books.

Liu JH, Goldstein-Hawes R, Hilton D, et al. (2005) Social representations of events and people in world history across 12 cultures. *J. Cross-Cult. Psychol.* 36(2): 1–21.

Lotman YM (1990) *Universe of the Mind: A Semiotic Theory of Culture*. Bloomington: Indiana University Press.

Lukes S (1977) Methodological individualism reconsidered. In: Lukes S (ed.) *Essays in Social Theory*, pp. 177–186. New York: Columbia University Press.

MacIntyre A (1984) *After Virtue: A Study in Moral Theory*. Notre Dame, IN: University of Notre Dame Press.

MacPherson M (2002) *Long Time Passing: Vietnam and the Haunted Generation*. New York: Doubleday.

Mannheim K (1951) The problem of generations. In: Kecskemeti P (ed.) *Essays on the Sociology of Knowledge*, pp. 276–320. London: Routledge and Kegan Paul.

McAdams DP (1993) *The Stories We Live By: Personal Myths and the Making of the Self*. New York NY: W. Morrow.

McCloskey M, Wible CG, and Cohen NJ (1988) Is there a special flashbulb-memory mechanism? *J. Exp. Psychol. Gen.* V117: 171–181.

Middleton D and Brown SD (2005) *The Social Psychology of Experience: Studies in Remembering and Forgetting*. San Francisco: Sage.

Mink LO (1978) Narrative form as a cognitive instrument. In: Canary RH and Kozicki H (eds.) *The Writing of History: Literary Form and Historical Understanding*, pp. 129–149. Madison: University of Wisconsin Press.

Neisser U (1982) Snapshots or benchmarks? In: Neisser U (ed.) *Memory Observed. Remembering in Natural Contexts*, pp. 43–49. San Francisco: Freeman.

Neisser U, Winograd E, Bergmann ET, Schreiber CA, Palmer SE, and Weldon MS (1996) Remembering the earthquake: Direct experience vs. hearing the news. *Memory* 4: 337–357.

Novick P (1999) *The Holocaust in American Life*. Boston: Houghton Mifflin.

Olick JK (1999) Collective memory: The two cultures. *Sociol. Theory* 17(3): 333–348.

Orwell G (1949) *Nineteen Eighty-Four*. New York: Harcourt Brace.

Overy R (1997) *Why the Allies Won*. New York: Norton.

Pennebaker JW and Banasik BL (1997) On the creation and maintenance of collective memories: History as social psychology. In: Pennebaker JW, Paez D, and Rimé B (eds.) *Collective Memory of Political Events: Social Psychological Perspectives*, pp. 3–19. Mahwah, NJ: Lawrence Erlbaum.

Pennebaker JW, Paez D Rimé (eds.) (1997) *Collective Memory of Political Events: Social Psychological Perspectives*, Mahwah, NJ: Lawrence Erlbaum.

Pillemer DB (1998) *Momentous Events, Vivid Memories: How Unforgettable Moments Help Us Understand the Meaning of Our Lives*. Cambridge, MA: Harvard University Press.

Pillemer DB and White SH (1989) Childhood events recalled by children and adults. In: Reese HW (ed.) *Advances in Child Development and Behavior,* vol. 21, pp. 297–340. Orlando: Academic Press.

Propp V (1968) *Morphology of the Folktale*, Scott L (trans.). Austin, TX: University of Texas Press.

Renan E (1990) What is a nation? In: Bhabha HK (ed.) *Nation and Narration.* London: Routledge.

Ricoeur P (1985) *Time and Narrative*, vol. 2, McLaughlin K and Pellauer D (trans.) Chicago: University of Chicago Press.

Roediger HL (1990) Implicit memory: Retention without remembering. *Am. Psychol.* 45: 1043–1056.

Roediger HL (2000) Sir Frederic Bartlett: Experimental and applied psychologist. In: Kimble GA and Wertheimer M (eds.) *Portraits of Pioneers in Psychology,* Vol. IV, pp. 149–161. Washington, DC: American Psychological Association.

Rubin DC, Wetzler SE, and Nebes RD (1986) Autobiographical memory across the lifespan. In: Rubin DC (ed.) *Autobiographical Memory*, pp. 225–252. New York: Cambridge University Press.

Rubin DC, Rahhal TA, and Poon LW (1998) Things learned in early adulthood are remembered best. *Mem. Cogn.* 26: 3–19.

Schacter DL (1994) Priming and multiple memory systems: Perceptual mechanisms of implicit memory. In: Schacter DL and Tulving E (eds.) *Memory Systems*. Cambridge, MA: MIT Press.

Schacter DL (1996) *Searching for Memory: The Brain, the Mind, and the Past*. New York: Basic Books.

Schudson M (1992) *Watergate in American Memory: How We Remember, Forget, and Reconstruct the Past*. New York: Basic Books.

Schuman H and Rodgers WL (2004) Cohorts, chronology, and collective memories. *Publ. Opin. Q.* 68(2): 217–254.

Schuman H and Scott J (1989) Generations and collective memories. *Am. Sociol. Rev.* 54: 359–381.

Schuman H, Belli RF, and Bischoping K (1997) The generational basis of historical knowledge. In: Pennebaker JW, Paez D, and Rimé B (eds.) *Collective Memory of Political Events: Social Psychological Perspectives*, pp. 47–77. Mahwah, NJ: Lawrence Erlbaum.

Schuman H, Schwartz B, and D'Arcy H (2005) Elite revisionists and popular beliefs: Christopher Columbus, hero or villain? *Public Opin. Q.* 69(1): 2–29.

Sellar WC and Yeatman RJ (1931) *1066 and All That: A Memorable History of England, Comprising All the Parts You Can Remember Including One Hundred and Three Good Things, Five Bad Kings and Two Genuine Dates*. New York: EP Dutton.

Smith RM (2003) *Stories of Peoplehood: The Politics and Morals of Political Membership*. Cambridge: Cambridge University Press.

Thapar R (2003) The rewriting of history and contemporary politics in India. Presentation at Washington University in St. Louis. May 2, 2003.

Tulving E and Schacter DL (1990) Priming and human memory systems. *Science* 247: 301–306.

Tulviste P and Wertsch JV (1994) Official and unofficial histories: The case of Estonia. *J. Narr. Life Hist.* 4(4): 311–329.

Wertsch JV (2002) *Voices of Collective Remembering*. New York: Cambridge University Press.

White H (1981) The value of narrativity in the representation of reality. In: Mitchell WJT (ed.) *On Narrative*, pp. 1–23. Chicago: University of Chicago Press.

Yates F (1966) *The Art of Memory*. Chicago: University of Chicago Press.

Zerubavel E (1997) *Social Mindscapes: An Invitation to Cognitive Sociology*. Cambridge, MA: Harvard University Press.

Zerubavel E (2003) *Time Maps: Collective Memory and the Social Shape of the Past*. Chicago: University of Chicago Press.