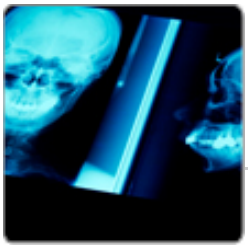

Human Memory

Jeffrey D. Karpicke, **Melissa Lehman**

Introduction

"Memory," broadly defined, is the ability to use the past in the service of the present. Memory can manifest itself in a variety of ways. When people tie their shoelaces or ride bicycles, they rely on past experiences to execute sequences of motor behaviors that accomplish those tasks. Such skills are often considered examples of *procedural memory*. When people identify objects in the environment (e.g., knowing that a thing is a plant or an animal) or when they give the answer to a factual question, they draw upon stores of general knowledge about the world accumulated over time. This type of memory is often referred to as *semantic memory*. When people remember events, they must attempt to recollect the details of what occurred at a particular place and time. This type of memory, called *episodic memory*, has been the focus of a wealth of research and will receive most of the attention in this article. Cognitive psychologists have devised numerous ways to study memory. Many methods involve giving a person various materials (often lists of words in laboratory experiments) during a study episode and then assessing that person's ability to remember the materials on a memory test. Consider the difference between episodic and semantic memory in this context. If the word "tiger" occurs on a list in a study episode, and a person in the experiment fails to remember it on a memory test, he or she did not momentarily forget that a tiger is a large cat with stripes and big teeth. Instead, the person failed to remember that "tiger" occurred in a particular place and time (on a particular list in a particular memory experiment). The study of human learning and memory is vast, and the goal of the present article is to help orient new students of memory to the lay of the land in memory research. There is a great deal of research on memory that spans a wide variety of methods and disciplines, from the study of neural mechanisms of memory in invertebrate animals to the study of collective memories for historical events passed down across generations. Complete coverage of the entire world of memory studies would be impossible in a single article. This article is focused primarily on the study of human episodic memory within the field of cognitive psychology.

General Overviews

A wide range of books has been written on human learning and memory. These include popular press books aimed at general nonexpert readers (such as Schacter 1996 and Schacter 2001); textbooks intended for undergraduate and graduate students (Eichenbaum 2008, Neath and Surprenant 2003); and edited volumes that contain chapters on specific topics written by the best memory researchers in the world (Craik and Tulving 2000; Roediger 2008; Roediger, et al. 2007). The scope of human memory studies is vast, with studies ranging from immediate memory for briefly presented visual displays, to long-term memory for personal life events, to a culture's collective memories for certain historical events (Boyer and Wertsch 2009) all falling within its purview. It is therefore fortunate that this array of excellent comprehensive overviews exists.

Boyer, P., and J. V. Wertsch, eds. 2009. *Memory in mind and culture*. Cambridge, UK: Cambridge Univ. Press.

This book contains chapters on various topics related to memory considered very broadly, including collective remembering of events by societies and the construction of history.

Craik, F. I. M., and E. Tulving, eds. 2000. *The Oxford handbook of memory*. Oxford: Oxford Univ. Press.

This handbook contains several chapters written by leading experts in the field of human learning and memory that are accessible to advanced students.

Eichenbaum, H. 2008. *Learning and memory*. New York: W. W. Norton.

This textbook provides an introduction to research on human memory and animal learning from an interdisciplinary perspective.

Neath, I., and A. M. Surprenant. 2003. *Human memory: An introduction to research, data, and theory*. 2d ed. Belmont, CA: Wadsworth.

This textbook is aimed at advanced undergraduate students and provides a comprehensive foundation for the study of human memory, including an introduction to mathematical and computational models of human memory.

Roediger, H. L., ed. 2008. *Learning and memory: A comprehensive reference*. Vol. 2, *Cognitive psychology of memory*. Editor-in-chief: J. Byrne. Oxford: Elsevier.

This volume is comprehensive, containing forty-eight chapters with extensive coverage of a wide range of topics, all within the broad category of memory studies.

Roediger, H. L., Y. Dudai, and S. M. Fitzpatrick, eds. 2007. *Science of memory: Concepts*. Oxford: Oxford Univ. Press.

This volume contains several brief chapters by memory experts on sixteen core concepts in the science of memory.

Schacter, D. L. 1996. *Searching for memory: The brain, the mind, and the past*. New York: Basic Books.

A highly readable book about the science of memory, written for a general audience. Schacter covers memory research on normal memory function and memory disorders associated with brain injuries.

Schacter, D. L. 2001. *The seven sins of memory: How the mind forgets and remembers*. Boston: Houghton Mifflin.

Another excellent book aimed at a general audience. Schacter discusses ways that memory sometimes fails, organized around seven “sins,” and also explains why certain occasional failures are part of a normal, functional memory system.

Journals

Research on human learning and memory is published in a variety of experimental and cognitive psychology journals. However, the journals Journal of Experimental Psychology: Learning, Memory, and Cognition, Journal of Memory and Language, Memory, and Memory & Cognition, in particular, are focused explicitly on publishing human learning and memory research. Although some journals focus specifically on memory research (Memory), others cover a wider range of topics within cognitive psychology (Journal of Experimental Psychology: Learning, Memory, and Cognition, Journal of Memory and Language, and Memory & Cognition). Additionally, some journals are specifically focused on the neuroscience side of memory research (Learning and Memory, and Neurobiology of Learning and Memory).

Journal of Experimental Psychology: Learning, Memory, and Cognition. 1975–.

This journal publishes original basic experimental research on topics in learning and memory, along with other areas of cognitive psychology, including problem solving, decision making, and language.

Journal of Memory and Language. 1962–.

This journal places a strong emphasis on theory, publishing theoretical papers related to memory and language processes, along with experimental work that makes a significant theoretical contribution in these research areas.

Learning & Memory. 1994–.

This journal publishes both original research reports and review articles on the topic of learning and memory in a neurobiological context, including research in human and animal populations.

Memory. 1993–.

This journal is specifically focused on human memory and includes both basic and applied experimental research on memory from laboratory and field settings. The work in this journal cuts across psychological disciplines; it includes memory research done by cognitive psychologists, along with educational, developmental, social, physiological, and clinical psychology researchers.

Memory & Cognition. 1973–.

This journal covers research on human memory and learning, along with other related cognitive processes, including decision making, problem solving, cognitive development, and mathematical and computer models of cognition.

Neurobiology of Learning and Memory. 1963–.

This journal on the neurobiology of learning and memory is focused largely on behavioral plasticity and mostly publishes research on animal learning, though it also includes some research on the neurobiological processes involved in human learning and memory.

Varieties of Memory

As noted in the Introduction, *memory* refers to a multitude of abilities and capacities. As such, grappling with the concept of memory can be challenging. Philosophers have wondered about the human mind and memory for centuries, and the writings of Plato and Aristotle contained early musings about the ability to remember the past. Hermann Ebbinghaus, a German psychologist who conducted the first systematic laboratory experiments on human memory, devoted significant attention in his great book, *Über das Gedachtnis*, to issues surrounding the conceptualization of memory (Ebbinghaus 1964). Whereas Ebbinghaus and his intellectual descendants tended to view memory as reproductive (associations were formed in the mind and reproduced when needed), Sir Frederick Charles Bartlett emphasized that memory is reconstructive (Bartlett 1932). Even after 125 years of experimental research on memory, there is no universally agreed upon organizational scheme, like a periodic table, for the many varieties of memory. The items in this section provide an overview and history of ways that scientists have attempted to conceptualize and classify types of memory (Roediger, et al. 2002; Squire 2004; Tulving 1972; Tulving 2002) and discuss some of the influential models of memory (Atkinson and Shiffrin 1968).

Atkinson, R. C., and R. M. Shiffrin. 1968. Human memory: A proposed system and its control processes. In *The psychology of learning and motivation*. Vol. 2. Edited by K. W. Spence and J. T. Spence, 89–195. New York: Academic Press.

During the “cognitive revolution” in the 1950s and 1960s, psychology researchers began to develop computational models of how mental processes work. Atkinson and Shiffrin proposed a detailed computational model of human memory that proposed separate memory stores (sensory memory, short-term memory, and long-term memory) and pointed to rehearsal as an important process for learning.

Bartlett, F. C. 1932. *Remembering: A study in experimental and social psychology*. Cambridge, UK: Cambridge Univ. Press.

Bartlett pointed out that people make systematic errors when attempting to remember events, errors that simple verbatim recording devices would not make. Today, Bartlett's influence on the science of memory is tantamount to that of Ebbinghaus.

Ebbinghaus, H. 1964. *Memory: A contribution to experimental psychology*. Translated by H. A. Ruger and C. E. Bussenius. New York: Dover.

Originally published in 1885, Ebbinghaus's landmark book commenced the scientific study of human memory. He laid the groundwork for all future experimental research on memory by devising methods of manipulating and assessing learning and memory and by discovering several important, fundamental findings.

Roediger, H. L. 1980. Memory metaphors in cognitive psychology. *Memory & Cognition* 8:231–246.

Roediger provides a history and overview of metaphors used to describe memory. The most pervasive view is a spatial storage and search metaphor, wherein mind/memory is viewed as a space and remembering involves searching through information stored in that space. Perhaps Roediger's most important point is that considering new, alternative metaphors would help enrich our conceptualization of memory.

Roediger, H. L., E. Marsh, and S. Lee. 2002. Varieties of memory. In *Stevens' handbook of experimental psychology*. Vol. 2, *Memory and cognitive processes*. 3d ed. Edited by D. L. Medin and H. Pashler, 1–41. New York: Wiley.

This chapter by Roediger, Marsh, and Lee shares the title of this section and provides excellent coverage of ways scientists have attempted to classify the many varieties of memory.

Squire, L. R. 2004. Memory systems of the brain: A brief history and current perspective. *Neurobiology of Learning and Memory* 82:171–177.

In this paper, Squire reviews research on the varieties of memory and different systems in the brain that are associated with different forms of memory. Available online for purchase or by subscription.

Tulving, E. 1972. Episodic and semantic memory. In *Organization of memory*. Edited by E. Tulving and W. Donaldson, 381–403. New York: Academic Press.

In this landmark chapter, Tulving coined the distinction between semantic and episodic memory. Whereas semantic memory refers to general knowledge about the world, episodic memory refers to the ability to remember what occurred at a particular place and time.

Tulving, E. 2002. Episodic memory: From mind to brain. *Annual Review of Psychology* 53:1–25.

This paper is a thirty-year retrospective on the distinction between episodic and semantic memory. Tulving outlines how the concept of episodic memory has evolved and grown, and he reviews evidence, especially from cognitive neuroscience research, supporting the distinction between these two types of memory.

Retrieval Processes

The next sections are focused on a few of the core concepts in the scientific study of memory. An important idea is that each experience leaves behind some kind of *memory trace*, a representation of the event, in a person's mind/brain. The exact nature of memory traces has not been specified by memory scientists (see Moscovitch 2007), but the idea that memory traces exist is useful for explaining memory phenomena. *Retrieval*, then, refers to processes involved in reconstructing what occurred at a particular place and time. Memory scientists assume that retrieval processes are always initiated by *retrieval cues*, identifiable triggers for retrieval processes, and that the experience of remembering occurs when retrieval cues interact with information in memory traces. For example, if your friend asks you, "What did you do last night?" that question serves as the retrieval cue for you to try to remember events from a past time and place. There must be some information about what you did last night stored in your mind (a memory trace), and your remembrance of the past happens because the retrieval cue interacts with the trace information. This section highlights foundational research and review articles on retrieval processes, beginning with Tulving's influential work on the importance of retrieval cues (Tulving 1974, Tulving and Pearlstone 1966). Raaijmakers and Shiffrin 1981 describes an influential and detailed model of retrieval processes. Nairne 2006 provides an accessible introduction to the idea that the distinctiveness or uniqueness of retrieval cues is a critical determinant of remembering. Roediger and Guynn 1996 provides an excellent review of research on retrieval processes.

Moscovitch, M. 2007. Memory: Why the engram is elusive. In *Science of memory: Concepts*. Edited by H. L. Roediger, Y. Dudai, and S. M. Fitzpatrick, 17–21. New York: Oxford Univ. Press.

Moscovitch provides an accessible and brief chapter explaining why it is difficult (perhaps even impossible) to study memory "traces."

Nairne, J. S. 2006. Modeling distinctiveness: Implications for general memory theory. In *Distinctiveness and memory*. Edited by R. R. Hunt and J. Worthen, 27–46. New York: Oxford Univ. Press.

Nairne describes a memory theory related to the principle of distinctiveness—the degree to which a cue uniquely specifies a target in a given context. This paper discusses data that relate to this principle and also evaluates the distinctiveness model in relation to other models of memory.

Raaijmakers, J. G. W., and R. M. Shiffrin. 1981. Search of associative memory. *Psychological Review* 88:93–134.

This paper provides an in-depth account of the complexities of retrieval processes. Raaijmakers and Shiffrin proposed an influential computational model of memory known as the Search of Associative Memory or "SAM" model. An extension of the Atkinson and Shiffrin 1968 model (cited under Varieties of Memory), the SAM model conceptualizes retrieval as a cue-driven search through information stored in memory. Available online for purchase or by subscription.

Roediger, H. L., and M. J. Guynn. 1996. Retrieval processes. In *Memory*. Edited by E. L. Bjork and R. A. Bjork, 197–236. San Diego, CA: Academic Press.

This chapter provides a comprehensive review of retrieval processes, including coverage of various ways retrieval can be measured and how retrieval processes interact with encoding processes (see Encoding-Retrieval Interactions).

Tulving, E. 1974. Cue-dependent forgetting. *American Scientist* 62:74–82.

Tulving conducted a series of important experiments on retrieval cueing effects in the late 1960s and early 1970s. This paper provides an overview of those experiments supporting the fundamental point that memory performance depends on the particular cues present in a given context.

Tulving, E., and Z. Pearlstone. 1966. Availability versus accessibility of information in memory for words. *Journal of Verbal*

***Learning and Verbal Behavior* 5:381–391.**

Tulving and Pearlstone made a subtle but important point: just because a person cannot recall something under certain conditions does not mean that all traces of that experience have vanished. Rather, the failure to recall may be due the absence of the appropriate retrieval cue. Available online for purchase or by subscription.

Encoding Processes

“Encoding” refers to the processes involved in the transformation of an event in the world into a representation in your mind/brain. By analogy, imagine that you are writing or speaking to a friend in a secret code: you have a message, and you transform that message into the code with the hopes that your friend can decode it (akin to retrieval). Similarly, memory scientists assume that events are transformed into mental representations by encoding processes. A considerable amount of memory research has examined ways that events are encoded by manipulating the way people process materials during study episodes. Generally speaking, the encoding of an event can be relatively impoverished or enriched (Craik 2002, Craik and Tulving 1975), and memory scientists have identified several encoding factors that tend to promote good memory performance. This section highlights several examples of encoding processes that typically enhance memory, including review papers on spacing and repetition effects (Greene 2008), generation effects (Mulligan and Lozito 2004), and effects of mental imagery (Cornoldi, et al. 2008). Hunt and McDaniel 1993 discusses how both organization and distinctiveness during encoding contribute to memory. Finally, Nairne and Pandeirada 2008 provides an overview of recent research on adaptive memory, specifically the finding that thinking about the fitness-relevance of materials improves memory.

Cornoldi, C., R. De Beni, and I. C. Mammarella. 2008. Mental imagery. In *Learning and memory: A comprehensive reference*. Vol. 2, *Cognitive psychology of memory*. Edited by H. L. Roediger, 103–123. Oxford: Elsevier.

The role of mental imagery in memory has been discussed for thousands of years, dating back to the writings of the ancient Greeks. Cornoldi, De Beni, and Mammarella provide a contemporary overview of research on the role of mental imagery in learning and memory.

Craik, F. I. M. 2002. Levels of processing: Past, present . . . and future? *Memory* 10:305–318.

Craik presents an updated view of the levels-of-processing framework and discusses the history, criticisms, and potential future directions for this important idea. Available online for purchase or by subscription.

Craik, F. I. M., and E. Tulving. 1975. Depth of processing and the retention of words in episodic memory. *Journal of Experimental Psychology: General* 104:268–294.

In this classic paper, Craik and Tulving examined the effects of the level, or depth, of processing during encoding, thought to be an important determinant of later memory. When people studied words and thought about their physical features (shallow processing) or their meaning (deep processing), they recalled and recognized more words processed deeply than words processed shallowly.

Greene, R. L. 2008. Repetition and spacing effects. In *Learning and memory: A comprehensive reference*. Vol. 2, *Cognitive psychology of memory*. Edited by H. L. Roediger, 65–78. Oxford: Elsevier.

In his original 1885 experiments, Ebbinghaus (see Ebbinghaus 1964, cited under Varieties of Memory) noted that repeating items and spacing the repetitions apart (rather than massing or cramming them together) were two factors that improved learning and memory. Greene provides an excellent overview of the sizable research literature on repetition and spacing effects.

Hunt, R. R., and M. A. McDaniel. 1993. The enigma of organization and distinctiveness. *Journal of Memory and Language*

32:421–445.

This paper reviews research on the effects of organization and distinctiveness of items during encoding in list memory and proposes a way to reconcile seemingly contradictory findings—that similarity of list items and distinctiveness of list items are known to enhance memory. Available online for purchase or by subscription.

Mulligan, N. W., and J. P. Lozito. 2004. Self-generation and memory. In *Psychology of learning and motivation*. Vol. 45. Edited by B. Ross, 175–214. San Diego, CA: Elsevier.

Mulligan and Lozito provide a review of research on the *generation effect*, the finding that subjects tend to recall and recognize more target words when they generated those words during a study episode (e.g., by generating the antonym to *hot*—?) relative to when they simply read the words (e.g., reading the words *hot—cold*).

Nairne, J. S., and J. N. S. Pandeirada. 2008. Adaptive memory: Remembering with a Stone-Age brain. *Current Directions in Psychological Science* 17:239–243.

Nairne and Pandeirada provide a brief overview of an adaptive theory of memory. This theory takes as its starting point the idea that memory has evolved in order to enhance fitness. The results of such adaptations are apparent in memory: memory for events is improved when people think about the fitness-relevance of those events during encoding.

Encoding-Retrieval Interactions

There is perhaps only one law or principle in memory research, known as the *encoding specificity principle* (Tulving 1983, Tulving and Thomson 1973). This principle is often characterized as the idea that memory performance is best when encoding and retrieval conditions "match," but more precisely, the encoding specificity principle states that a retrieval cue, by itself, is not inherently powerful or effective. Instead, a cue is effective only when it was part of the original encoding event, and therefore the effectiveness of any retrieval cue depends on the conditions of the original encoding experience. This dependency relationship is known as an *encoding-retrieval interaction*. Roediger and Guynn 1996 (cited under Retrieval Processes) provides an excellent overview of many encoding-retrieval interactions. In addition to interactions among encoding and retrieval conditions, memory performance is also the product of complex interactions among features of the to-be-learned materials and aspects of individual learners, as noted in Jenkins 1979 and in the recent review Roediger 2008. The items in this section provide an introduction to how remembering depends on interactions among these four factors: properties of the learner, aspects of the materials, activities during encoding, and conditions at retrieval (see McDaniel and Bugg 2008, McDaniel and Einstein 1989).

Jenkins, J. J. 1979. Four points to remember: A tetrahedral model of memory experiments. In *Levels of processing in human memory*. Edited by L. S. Cermak and F. I. M. Craik, 429–446. Hillsdale, NJ: Erlbaum.

Jenkins pointed out that in any study of learning and memory there are four factors or "points" to consider: characteristics of subjects (learners), characteristics of the to-be-learned materials, characteristics of the encoding tasks, and characteristics of retrieval conditions. The study of learning and memory is inherently complex because there can be interactions among any of these four factors.

McDaniel, M. A., and J. M. Bugg. 2008. Instability in memory phenomena: A common puzzle and a unifying explanation. *Psychonomic Bulletin & Review* 15:237–255.

McDaniel and Bugg review several cases where properties of the materials (e.g., whether a to-be-learned list contains high- or low-frequency words) and properties of encoding tasks (e.g., whether subjects are instructed to read or generate words) interact with retrieval conditions on a memory test, and they outline useful theoretical tools for understanding these complex interactions.

McDaniel, M. A., and G. O. Einstein. 1989. Material-appropriate processing: A contextualist approach to reading and studying strategies. *Educational Psychology Review* 1:113–145.

McDaniel and Einstein describe *material-appropriate processing*, the idea that the effectiveness of different encoding or study strategies will depend on properties of the materials—in particular, the level of organization present in the materials. Available online for purchase or by subscription.

Nairne, J. S. 2002. The myth of the encoding–retrieval match. *Memory* 10:389–395.

Nairne challenges the assumption that memory is determined by the match between encoding and retrieval conditions and suggests instead that the diagnosticity of memory cues (i.e., the degree to which a cue matches a target item in relation to the degree to which a cue matches nontarget information) determines the probability of retrieval.

Roediger, H. L. 2008. Relativity of remembering: Why the laws of memory vanished. *Annual Review of Psychology* 59:225–254.

Roediger reiterates the main point made in Jenkins 1979 and describes several cases in which memory performance depends on the "four points" described in his original chapter. Available online for purchase or by subscription.

Tulving, E. 1983. *Elements of episodic memory*. New York: Oxford Univ. Press.

Tulving's landmark book is essential reading for any student of learning and memory. In particular, Tulving provides an overview of a wide variety of encoding-retrieval interactions in chapter 5 and details the development of the encoding specificity principle in chapters 10–14.

Tulving, E., and D. M. Thomson. 1973. Encoding specificity and retrieval processes in episodic memory. *Psychological Review* 80:359–380.

In this influential paper, Tulving and Thomson proposed the principle of encoding specificity, which states that memory will be best when information present during encoding is also present during retrieval. They discussed various other explanations of retrieval processes, along with data that are inconsistent with these other explanations.

Forgetting

After laying out the core ideas about encoding and retrieval processes, we now have a toolkit with which we can approach a wide range of memory phenomena. One of the fundamental topics in the study of learning memory, since the very beginning of memory research, has been forgetting (Nairne and Pandeirada 2008). Why is it that we fail to recall certain things that we were once able to recall? Throughout the 1950s and 1960s, the *interference theory of forgetting* was one of the central topics in the psychology of human learning and memory, and the general idea was that people forget events because of the occurrence of other interfering events (Anderson and Neely 1996, Crowder 1976). To use a concrete example, imagine that at the end of a workday you are trying to remember where you parked your car that morning. According to ideas from interference theory, there are two potential sources of interference that might lead you to forget where you parked. Events that occurred throughout the day might interfere with your memory, and the interference of events that occurred after the particular event you are trying to remember is called *retroactive interference*. In addition, your memory for other places you parked your car on previous days might interfere with your memory, and this type of interference produced by events that occurred before the event you are trying to remember is called *proactive interference*. Contemporary ideas about forgetting emphasize that forgetting occurs when retrieval cues become overloaded, specifying too many possible past events, and that forgetting

is actually an adaptive aspect of memory. That is, the fact that we do not recall all our past experiences is part of a functional and efficient learning and memory system, a point emphasized by Anderson and Schooler 1991, by Storm 2011, and in the edited volume by Benjamin 2011.

Anderson, J. R., and L. J. Schooler. 1991. Reflections of the environment in memory. *Psychological Science* 2:396–408.

Anderson and Schooler argued that the likelihood of remembering information is related to one's prior exposure to that information in the environment. In this paper, they present a model of memory that takes such factors into account. Available online for purchase or by subscription.

Anderson, M. C., and J. H. Neely. 1996. Interference and inhibition in memory retrieval. In *Memory*. Edited by E. L. Bjork and R. A. Bjork, 237–313. San Diego, CA: Academic Press.

This chapter is an extensive and thorough examination of the role of interference and inhibition processes in forgetting.

Benjamin, A. S., ed. 2011. *Successful remembering and successful forgetting: A Festschrift in honor of Robert A. Bjork*. New York: Psychology Press.

This volume contains various chapters discussing intentional and unintentional forgetting, including some chapters related to Robert A. Bjork's influential idea that forgetting is an adaptive process. Also included are chapters on learning, metamemory, aging, and memory illusions, all influenced by Bjork's work.

Crowder, R. G. 1976. *Principles of learning and memory*. Hillsdale, NJ: Erlbaum.

Crowder's excellent book summarizes a wealth of memory research conducted prior to the mid-1970s. Particularly noteworthy is his coverage of the interference theory of forgetting in chapter 8.

Nairne, J. S., and J. N. S. Pandeirada. 2008. Forgetting. In *Learning and memory: A comprehensive reference*. Vol. 2, *Cognitive psychology of memory*. Edited by H. L. Roediger, 179–194. Oxford: Elsevier.

An accessible, recent chapter outlining the history and major theories in the study of forgetting.

Storm, B. C. 2011. The benefit of forgetting in thinking and remembering. *Current Directions in Psychological Science* 20:291–295.

Storm presents a short review of research on the adaptive value of forgetting, emphasizing the importance of forgetting in reducing interference. Available online for purchase or by subscription.

Short-Term/Working Memory

A considerable amount of memory research has examined memory for small amounts of material (like short lists of digits or words) over short periods of time (immediately after presenting the list) to examine *short-term memory*. In *memory span tasks*, typically the goal is to determine the longest list a person can reproduce perfectly shortly after experiencing it (e.g., the longest list of random digits a person can recite back immediately after hearing them). In recent years, researchers have created tasks in which people perform memory span tasks concurrently with additional attention-demanding tasks. Because these tasks require people to maintain and "work with"

information in the face of distraction, performance on these tasks is referred to as a person's *working memory capacity*. Perhaps the most remarkable feature of measures of working memory is that there are a wide range of individual differences in the ability to perform working memory tasks, and performance on relatively simple working memory tasks predicts performance on a wide array of more complex cognitive abilities like reasoning, comprehension (Daneman and Carpenter 1980), and general intelligence (Conway, et al. 2003; Kane and Engle 2002). Baddeley and Hitch 1974 introduces the authors' well-known model of working memory. Cowan 1995 provides a detailed account of attention and memory, integrating the two into one system. Nairne 2002 challenges the standard view of short-term memory and proposed an alternative model.

Baddeley, A. D., and G. Hitch. 1974. Working memory. In *The psychology of learning and motivation: Advances in research and theory*. Vol. 8. Edited by G. H. Bower, 47–89. New York: Academic Press.

Baddeley and Hitch suggested that the concept of short-term memory, as proposed by Atkinson and Shiffrin 1968 (cited under Varieties of Memory), should be expanded to include multiple components for storing and manipulating information.

Conway, A. R., M. J. Kane, and R. W. Engle. 2003. Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences* 7.12: 547–552.

Conway, Kane, and Engle showed that working memory capacity is associated with general intelligence and reasoning abilities. Available online for purchase or by subscription.

Cowan, N. 1995. *Attention and memory: An integrated framework*. New York: Oxford Univ. Press.

Cowan presents a model of attention and memory that accounts for a variety of data on both processes, including data that challenge models of short-term memory. This book also discusses brain processes in relation to the model.

Daneman, M., and P. A. Carpenter. 1980. Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior* 19.4: 450–466.

This paper is important because it introduces Daneman and Carpenter's commonly used reading span task, which measures the storage and processing functions of working memory by measuring the number of sentences a person can read while remembering the last word from each sentence. They showed that participants with higher reading spans scored higher on measures of text comprehension. Available online for purchase or by subscription.

Kane, M. J., and R. W. Engle. 2002. The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review* 9.4: 637–671.

This paper provides a useful review of literature on working memory and individual differences in working memory ability, and also discusses the role of the prefrontal cortex in working memory function. Available online for purchase or by subscription.

Nairne, J. S. 2002. Remembering over the short-term: The case against the standard model. *Annual Review of Psychology* 53:53–81.

In this paper, Nairne argues against the common conceptualization of short-term memory as a set of activated information and describes a variety of findings that are inconsistent with this view. He suggests alternatively that, like long-term memory, short-term memory is cue driven, and the same general memory principles operate at both short and long time intervals. Available online for purchase or by subscription.

Amnesia

One of the ways cognitive psychologists study various mental phenomena is by examining cognitive systems when they fail. Such is the case with amnesia, which in general refers to the loss of memory abilities as a result of some form of brain injury. There are two general classes of amnesia. The loss of memory for events that occurred prior to brain injury is called *retrograde amnesia*, whereas the loss of the ability to create new memories for events occurring after brain injury is called *anterograde amnesia*. The deficits exhibited by amnesic patients have provided insights into the workings of normal memory systems and into the brain structures that are critical for learning and memory, namely the hippocampus and surrounding structures in the medial temporal lobes. The works cited here represent important papers and general overviews of research with amnesic patients, including the Scoville and Milner 1957 description of H. M. (see also Hilts 1995), and the Rosenbaum, et al. 2005 case study of K. C., two individuals with severe episodic amnesia. Squire, et al. 2004 reviews brain areas relevant to memory and the memorial implications of damage to these areas.

Hilts, P. J. 1995. *Memory's ghost: The nature of memory and the strange tale of Mr. M.* New York: Simon and Schuster.

This book, written for a general audience, provides an overview of the famous amnesic patient H. M., detailing aspects of his life and his memory abilities.

Rosenbaum, R. S., S. Kohler, D. L. Schacter, et al. 2005. The case of K. C.: Contributions of a memory-impaired person to memory theory. *Neuropsychologia* 43:989–1021.

This paper reviews the case of K. C., an individual who suffered brain damage resulting in robust episodic amnesia with intact semantic memory. The case of K. C. has been important to memory research on the distinction between episodic and semantic memory, and this paper reviews a large amount of research involving K. C.

Scoville, W. B., and B. Milner. 1957. Loss of recent memory after bilateral hippocampal lesions. *Journal of Neurology, Neurosurgery, and Psychiatry* 20:11–21.

This paper describes various case studies involving individuals who had damage to brain areas related to memory, most notably, the case of the patient H. M., a man who had part of his temporal lobe and surrounding brain area (including the hippocampus) removed to cure severe seizures, resulting in an inability to form new memories after the surgery.

Squire, L. R., C. E. L. Stark, and R. E. Clark. 2004. The medial temporal lobe. *Annual Review of Neuroscience* 27:279–306.

This paper reviews the memory functions of several distinct structures within the medial temporal lobe, drawing in part from decades of research on amnesic patients. Available online for purchase or by subscription.

Priming and Implicit Memory

If we define memory as the ability to use the past in the service of the present, it is easy to see that there are many times when people rely on past experiences without consciously, deliberately remembering those experiences. To tie your shoes or ride a bicycle, you need not recollect prior times when you practiced those skills, yet your prior experiences are what enable you perform those tasks. Memory researchers use the term "priming" to refer to influences of past experiences on current performance in the absence of conscious recollection of the past (Tulving and Schacter 1990). Many of the methods of testing memory described above, such as recall and recognition tests, require people to think back and remember what occurred in a particular episode or study event. These methods of testing memory are called *explicit tests*. In contrast, there are many methods of assessing what people have retained about prior experiences that do not require them to think back to any past episodes. These methods of testing memory are called *implicit tests* and

they are intended to assess priming. The distinction between explicit and implicit memory tests emerged from research with amnesic patients, who despite showing dramatic deficits on explicit measures of memory will often show intact levels of priming on implicit memory tests (Warrington and Weiskrantz 1970). Jacoby's work highlights some of the dissociations between implicit and explicit memory (Jacoby and Dallas 1981), and Jacoby 1991 describes a procedure for measuring automatic versus intentional memory processes. Cognitive psychologists have been studying priming on implicit memory tests since the middle of the 20th century, and the articles included here highlight some of the foundational contributions in this area (see Roediger 1990 and Schacter 1987 for reviews).

Jacoby, L. L. 1991. A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language* 30.5: 513–541.

In this paper, Jacoby describes the process dissociation procedure, an influential memory task proposed to identify automatic memory processes resulting from feelings of familiarity and intentional memory processes resulting from the recollection of details about events. Available online for purchase or by subscription.

Jacoby, L. L., and M. Dallas. 1981. On the relationship between autobiographical and perceptual learning. *Journal of Experimental Psychology: General* 110:306–340.

Jacoby and Dallas explored various factors that affect implicit and explicit memory differently, including depth of processing, task difficulty, repetition, and study time.

Roediger, H. L. 1990. Implicit memory: Retention without remembering. *American Psychologist* 45:1043–1056.

This paper provides a useful review of literature on implicit memory and discusses similarities and dissociations between implicit and explicit memory. Available online for purchase or by subscription.

Schacter, D. L. 1987. Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 13:501–518.

This is another review of research on implicit memory, which discusses dissociations in amnesia in detail.

Tulving, E., and D. L. Schacter. 1990. Priming and human memory systems. *Science* 247 (1940): 301–306.

This paper provides a short but thorough overview of priming, especially focused on neuropsychological research on priming. Available online for purchase or by subscription.

Warrington, E. K., and L. Weiskrantz. 1970. Amnesic syndrome: Consolidation or retrieval? *Nature* 228:628–630.

Warrington and Weiskrantz examined memory in amnesic patients and normal subjects and found that while amnesic patients were impaired on explicit memory tests like recall and recognition, they were not impaired on implicit tests like word fragment completion. Available online for purchase or by subscription.

Memory Illusions

Our minds/brains do not store exact, verbatim copies of the past. Instead, people use retrieval cues to try to reconstruct what occurred in the past based on fragmented, imperfect traces of prior experiences. It is therefore not surprising that human memory can be prone to

errors and distortions, but what may be surprising is the compelling subjective experience of true remembering that can sometimes accompany such false memories. Cognitive psychologists have designed several methods for eliciting illusory memories in order to study them in the laboratory (Roediger and McDermott 1995). Memory researchers have also sought to explore the implications of memory illusions for remembering in real-world scenarios, especially regarding eyewitness memory for complex events (Loftus 1992; Loftus, et al. 1987; Loftus and Palmer 1974). This section highlights important books (Brainerd and Reyna 2005, Gallo 2006) and key papers (Roediger 1996) on the study of false memories.

Brainerd, C. J., and V. F. Reyna. 2005. *The science of false memory*. Oxford: Oxford Univ. Press.

Brainerd and Reyna's book examines research on memory illusions from a variety of approaches, including research on false memories in criminal investigations and therapy contexts.

Gallo, D. A. 2006. *Associative illusions of memory: False memory research in DRM and related tasks*. New York: Psychology Press.

This book provides an in-depth review of research on false memories in the Deese-Roediger-McDermott paradigm (Roediger and McDermott 1995), discussing relevant research in cognitive psychology, neuroscience, and neuropsychology.

Loftus, E. F. 1992. When a lie becomes memory's truth: Memory distortion after exposure to misinformation. *Current Directions in Psychological Science* 1:121–123.

This paper reviews various factors that contribute to the misinformation effect, the tendency for people's memories for an event to be affected by misleading information received after the event. Available online for purchase or by subscription.

Loftus, E. F., G. R. Loftus, and J. Messo. 1987. Some facts about "weapon focus." *Law and Human Behavior* 11:55–62.

This paper discusses "weapon focus," the finding that the presence of a weapon during an event draws attention and reduces memory for other details of the event. Available online for purchase or by subscription.

Loftus, E. F., and J. C. Palmer. 1974. Reconstruction of automobile destruction: An example of the interaction between language and memory. *Journal of Verbal Learning and Verbal Behavior* 13:585–589.

This highly cited paper describes an experiment in which Loftus and Palmer showed subjects a video of an automobile accident and manipulated the wording of questions given to participants after viewing the video. Subjects' memories for the event one week later were influenced by the questions they were asked after the event, suggesting that information presented after an event can distort one's memory for the event. Available online for purchase or by subscription.

Roediger, H. L. 1996. Memory illusions. *Journal of Memory and Language* 35:76–100.

This article introduced a special issue of the *Journal of Memory and Language* dedicated to memory illusions. It discusses the various memory illusions studied by cognitive psychologists, along with the history of this research. Available online for purchase or by subscription.

Roediger, H. L., and K. B. McDermott. 1995. Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 21:803–814.

This paper describes a procedure for creating false memories in the lab, commonly referred to as the Deese-Roediger-McDermott paradigm, in which lists of items were presented, each consisting of a set of items associated with an unpresented word. Subjects frequently incorrectly recalled and recognized the unpresented word. Available online for purchase or by subscription.

Metamemory

This section highlights an intriguing and important aspect of human learning and memory: the fact that people have knowledge about their own learning and memory processes. Knowledge about one's own cognitive processes, in general, is referred to as *metacognition*, and when we refer to people's knowledge about their own learning and memory processes we use the term "metamemory" (Dunlosky and Metcalfe 2009). Metamemory processes are often divided into *monitoring processes*, which refer to processes involved in assessing our own knowledge, and *control processes*, which refer to regulatory and decision processes people execute based on their metacognitive monitoring (Koriat and Goldsmith 1996, Nelson and Narens 1990). For example, when we retrieve knowledge, we are able to monitor information about the source of our knowledge (e.g., whether we read about an event, or imagined it, or actually experienced it, and so on; Johnson 2006; Johnson, et al. 1993). When recollecting events, we can state that we have a vivid experience of *remembering* the prior occurrence, or we might say we are sure it occurred even though we do not have the vivid experience of remembering (Tulving 1985). Similarly, we can indicate our level of *confidence* in our memories and knowledge. When we are trying to learn new things, we can assess how well we think we are doing, a rating known as a *judgment of learning*. Metamemory also refers to how we use our subjective experiences to regulate and control our behavior (e.g., how we use confidence to decide whether to claim that we have a true memory for an event, or how we use judgments of learning to decide whether to continue or stop studying; Koriat 1997, Metcalfe 2009). The following papers touch on these core topics in the scientific study of metamemory.

Dunlosky, J., and J. Metcalfe. 2009. *Metacognition*. Thousand Oaks, CA: SAGE.

This textbook provides excellent coverage of key topics in the science of metamemory.

Johnson, M. K. 2006. Memory and reality. *American Psychologist* 61:760–771.

Johnson describes a theory of memory according to which information about actual events is combined with an individual's knowledge about the world along with knowledge of things that happened before or after the event in order to produce what we experience as memories. Available online for purchase or by subscription.

Johnson, M. K., S. Hashtroudi, and D. S. Lindsay. 1993. Source monitoring. *Psychological Bulletin* 114:3–28.

This paper provides a review of literature on source monitoring and discusses a framework for understanding source monitoring, along with brain areas associated with source monitoring and source misattribution errors. Available online for purchase or by subscription.

Koriat, A. 1997. Monitoring one's own knowledge during study: A cue utilization approach to judgments of learning. *Journal of Experimental Psychology: General* 126:349–370.

Koriat discusses the ways in which various types of cues influence judgments of learning and how this relates to the accuracy of those judgments. Across four experiments, he showed that intrinsic and extrinsic factors differentially affect judgments of learning and subsequent recall and that practice can shift reliance on intrinsic cues to reliance on extrinsic cues.

Koriat, A., and M. Goldsmith. 1996. Monitoring and control processes in the strategic regulation of memory accuracy. *Psychological Review* 103:490–517.

Koriat and Goldsmith's influential paper proposed a theory about how people monitor their confidence in their knowledge and memories and use confidence to regulate their decisions to call something a memory. Available online for purchase or by subscription.

Metcalfe, J. 2009. Metacognitive judgments and control of study. *Current Directions in Psychological Science* 18:159–163.

Metcalfe offers a concise overview of current theories about how people regulate and control their study choices. Available online for purchase or by subscription.

Nelson, T. O., and L. Narens. 1990. Metamemory: A theoretical framework and new findings. In *The psychology of learning and motivation: Advances in research and theory*. Vol. 26. Edited by G. H. Bower, 125–169. New York: Academic Press.

In this influential chapter, Nelson and Narens present a theory of metacognition, at the center of which are control processes and monitoring processes. This theory built a cohesive organizational structure that provided a framework for guiding new research on metacognition.

Tulving, E. 1985. Memory and consciousness. *Canadian Psychologist* 25:1–12.

Tulving introduced the remember/know distinction, the difference between remembering the episodic details of an event (referred to as autonoetic awareness) and simply knowing that the event occurred (referred to as noetic awareness). Available online for purchase or by subscription.

LAST MODIFIED: 04/22/2013

DOI: 10.1093/OBO/9780199828340-0107

BACK TO TOP

Index

Show related links | **Search across all sources** in