CHAPTER OUTLINE AND LEARNING OBJECTIVES

An Introduction to Memory
LO 1 Define memory.
LO 2 Describe the processes of encoding, storage, and retrieval.

Flow With It: Stages of Memory
LO 3 Explain the stages of memory described by the information-processing model.
LO 4 Describe sensory memory.
LO 5 Summarize short-term memory.
LO 6 Give examples of how we can use chunking to improve our memory span.
LO 7 Describe working memory and its relationship to short-term memory.
LO 8 Describe long-term memory.

Retrieval and Forgetting
LO 9 Illustrate how encoding specificity relates to retrieval cues.
LO 10 Identify and explain some of the reasons why we forget.

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LO 14 Identify the brain structures involved in memory.
LO 15 Describe long-term potentiation and its relationship to memory.
An Introduction to Memory

MEMORY BREAKDOWN: THE CASE OF CLIVE WEARING

Monday, March 25, 1985: Deborah Wearing awoke in a sweat-soaked bed. Her husband, Clive, had been up all night perspiring, vomiting, and with a high fever. He said that he had a “constant, terrible” headache, like a “band” of pain tightening around his head (Wearing, 2005, p. 27). The symptoms worsened over the next few days, but the two doctors caring for Clive reassured Deborah that it was just a bad case of the flu. By Wednesday, Clive had spent three nights awake with the pain. Confused and disoriented, he turned to Deborah and said, “Er, er, darling. . . . I can’t . . . think of your name” (p. 31).

The doctor arrived a couple of hours later, reassured Deborah that her husband’s confusion was merely the result of sleep deprivation, and prescribed sleeping pills. Deborah came home later that day, expecting to find her husband in bed. But no Clive. She shouted out his name. No answer, just a heap of pajamas. After the police had conducted an extensive search, Clive was found when a taxi driver dropped him off at a local police station; he had gotten into the cab and couldn’t remember his address (Wearing, 2005). Clive returned to his flat (which he did not recognize as home), rested, and took in fluids. His fever dropped, and it appeared that he was improving. But when he awoke Friday morning, his confusion was so severe he could not identify the toilet among the various pieces of furniture in his bathroom. As Deborah placed urgent calls to the doctor, Clive began to drift away. He lost consciousness and was rushed to the hospital in an ambulance (Wearing, 2005; Wilson & Wearing, 1995).

Prior to this illness, Clive Wearing had enjoyed a fabulous career in music. As the director of the London Lassus Ensemble, he spent his days leading singers and instrumentalists through the emotionally complex music of his favorite composer, Orlande de Lassus. A renowned expert on Renaissance music, Clive produced music for the prestigious British Broadcasting Corporation (BBC), including that which aired on the wedding day of Prince Charles and Lady Diana Spencer (Sacks, 2007, September 24; Wilson, Baddeley,
& Kapur, 1995; Wilson, Kopelman, & Kapur, 2008). But Clive’s work—and his whole life—tumbled into chaos when a virus that normally causes blisters on the mouth invaded his brain.

Millions of people carry herpes simplex virus type 1 (HSV-1). Usually, it causes unsightly cold sores on the mouth and face. (There is also HSV-2, more commonly associated with genital herpes.) But for a small minority of the adult population—as few as 1 in 500,000 annually—the virus invades the central nervous system and causes a life-threatening infection called encephalitis. Left untreated, herpes encephalitis causes death in over 70% of its victims. Most who survive have lasting neurological deficits (Sabah, Mulcahy, & Zeman, 2012; Sili, Kaya, Mert, & HSV Encephalitis Study Group, 2014).

Although Deborah saw to it that Clive received early medical attention, having two doctors visit the house day and night for nearly a week, these physicians mistook his condition for the flu with meningitis-like symptoms (Wilson & Wearing, 1995). Misdiagnosis is common with herpes encephalitis (even to this day), as its symptoms resemble those of other conditions, including the flu, meningitis, a stroke, and epilepsy (Sabah et al., 2012). When Clive and Deborah arrived at the hospital on the sixth day of his illness, they waited another 11 hours just to get a proper diagnosis (Wearing, 2005; Wilson & Wearing, 1995).

Clive survived, but the damage to his brain was extensive and profound; the virus had destroyed a substantial amount of neural tissue. And though Clive could still sing and play the keyboard (and spent much of the day doing so), he was unable to continue working as a conductor and music producer (D. Wearing, personal communication, June 18, 2013; Wilson & Wearing, 1995). In fact, he could barely get through day-to-day life. In the early stages of recovery, simple activities like eating baffled him. He ate the menu and attempted to spread cottage cheese on his bread, apparently mistaking it for butter. He confused basic concepts such as “scarf” and “umbrella,” and shaved his eyebrows and nose (Wearing, 2005; Wilson & Wearing, 1995).

In the months following his illness, Clive was overcome with the feeling of just awakening. His senses were functioning properly, but every sight, sound, odor, taste, and feeling registered for just a moment, and then vanished. As Deborah described it, Clive saw the world anew with every blink of his eye (Wearing, 2005). The world must have seemed like a whirlwind of sensations, always changing. Desperate to make sense of it all, Clive would pose the same questions time and again: “How long have I been ill?” he would ask Deborah and the hospital staff members looking after him. “How long’s it been?” (Wearing, 2005, p. 181). For much of the first decade following his illness, Clive repeated

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Clive and Deborah, in Their Own Words
http://qrs.ly/8m5a5d1

Looking at a page from Clive’s diary, you can see the fragmented nature of his thought process. He writes an entry, forgets it within seconds, and then returns to the page to start over, often writing the same thing. Encephalitis destroyed areas of Clive’s brain that are crucial for learning and memory, so he can no longer recall what is happening from moment to moment. Jiri Rezac/Polaris/Newscom.
the same few phrases almost continuously in his conversations with people. “I haven’t heard anything, seen anything, touched anything, smelled anything,” he would say. “It’s just like being dead” (p. 160).

The depth of Clive’s impairment is revealed in his diary, where he wrote essentially the same entries all day long. On August 25, 1985, he wrote, “I woke at 8:50 a.m. and bought [sic] a copy of *The Observer,*” which is then crossed out and followed by “I woke at 9:00 a.m. I had already bought a copy of *The Observer.*” The next line reads, “This (officially) confirms that I awoke at 9:05 a.m. this morning” (Wearing, 2005, p. 182). Having forgotten all previous entries, Clive reported throughout the day that he had just become conscious. His recollection of writing in his journal—along with every experience in his life—came and went in a flash. The herpes virus had ravaged his memory system.

The story of Clive Wearing launches our journey through memory. This chapter will take us to the opposite ends of a continuum: from memory loss to exceptional feats of remembering. We will explore the world of memory sport, learning tricks from some of the greatest memory athletes in the world. These strategies could help you remember material for exams and everyday life: terms, concepts, passwords, pin numbers, people’s names, and where you left your keys. You, too, can develop superior memorization skills; you just have to practice using memory aids. But beware: No matter how well you exercise your memory “muscle,” it does not always perform perfectly. Like anything human, memory is prone to error.

Three Processes: Encoding, Storage, and Retrieval

**LO 1 Define memory.**

Memory refers to the brain processes involved in the encoding (collection), storage, and retrieval of information. Much of this process has gone haywire for Clive. You may be wondering why we chose to start this chapter with the story of a person whose memory system failed. When it comes to understanding complex cognitive processes like those of memory, sometimes it helps to examine what happens when elements of the system are not working.

What is your earliest memory and how was it created? Do you know if it is accurate? And how can you recall it after so many years? Psychologists have been asking questions like these since the 1800s. Exactly how the brain absorbs information from the outside world and files it for later use is still not completely clear, but scientists have proposed many theories and models to explain how the brain processes, or works on, data on their way to becoming memories. As you learn about various theories and models, keep in mind that none of them are perfect. Rather than labeling one as right and another as wrong, most psychologists embrace a combination of approaches, taking into consideration their various strengths and weaknesses.

One often-used model likens the brain’s memory system to a computer. Think about how a computer operates: It receives data from external sources, like your fingers typing on the keyboard, and converts that data into a code it can manipulate. Once this is accomplished, the information can be saved on the hard drive so you can open up the documents, MP3s, and other data files you need. The brain’s memory system accomplishes similar tasks, but it is very different from a computer. Communication among neurons in the brain is more complicated than signals running between electrical components in a circuit. And unlike a computer, which maintains your files exactly how you last saved them, memories are subject to modifications over time, and this
means they may be somewhat different each time you access them. Finally, the brain has seemingly unlimited storage capabilities, and the ability to process many types of information simultaneously, both consciously and unconsciously. We don’t completely understand how a functioning memory system works, but there is basic agreement on its general processes, particularly encoding, storage, and retrieval.

**LO 2** Describe the processes of encoding, storage, and retrieval.

**ENCODING** During the course of a day, we are bombarded with information coming from all of our senses and internal data from thoughts and emotions. Some of this information we will remember, but the majority of it will not be retained for long. What is the difference between what is kept and what is not? Most psychologists agree that it all starts with encoding, the process through which information enters our memory system. Think about what happens when you pay attention to an event unfolding before you; stimuli associated with that event (sights, sounds, smells) are taken in by your senses and then converted to neural activity that travels to the brain. The information is processed and takes one of two paths: Either it enters our memory system (it is encoded to be stored for a longer period of time) or it slips away. For Clive Wearing, much of this information slips away.

**STORAGE** For information that is successfully encoded, the next step is storage. Storage is exactly what it sounds like: preserving information for possible recollection in the future. Before Clive Wearing fell ill, his memory was excellent. His brain was able to encode and store a variety of events and learned abilities. Following his bout with encephalitis, however, his ability for long-term storage of new memories was destroyed—he could no longer retain new information for more than seconds at a time.

**RETRIEVAL** After information is stored, how do we access it? Perhaps you still have a memory of your first-grade teacher’s face, but can you remember his or her name? This process of coming up with stored information (Ms. Nautiyal! Mr. Kopitz!) is called retrieval. Sometimes information is encoded and stored in memory but cannot be accessed, or retrieved. Have you ever felt that a person’s name or a certain vocabulary word was just sitting “on the tip of your tongue”? Chances are you were struggling from a retrieval failure, which we will discuss later in this chapter.

Before taking a closer look at the processes of memory, let’s give your memory system a little workout. Ready for a challenge?

**MEMORY: IT’S A SPORT** Give yourself 5 minutes to study the row of ones and zeros below. When 5 minutes are up, look away from your textbook and try to write down the exact sequence on a blank piece of paper.

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000101101011010011010101011100110001010100011100100100100100
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How did you do? Most people have a hard time remembering all 60 digits in 5 minutes, but there are individuals who can memorize hundreds in this short time. The current world record, held by Johannes Mallow of Germany, is 1,080. Here are a few other accomplishments of the world’s leading “memory athletes” (World Memory Sports Council, 2016a & b):

- **Connection** In Chapters 2 and 3, we described how sensory information is taken in by sensory receptors and transduced; that is, transformed into neural activity. Here, we explore what happens after transduction, when information is processed in the memory system.
• Alex Mullen of the United States memorized 3,029 decimal digits in 1 hour (for example, “2 7 6 4 3 0 9 7 2 8 8 4 3 . . .”).
• Simon Reinhard of Germany memorized an entire deck of playing cards in 20.44 seconds (for example, “7 of spades, jack of hearts, 3 of diamonds . . .”).
• Purevjav Erdenesaikhan of Mongolia memorized 112 random words in 5 minutes (for example, “dog, now, is, notebook, stinging . . .”).

MEMORY COMPETITORS AND THE REST OF US Who are these memory athletes, and how do they manage to pack so much information into their brains in so little time? Most are ordinary people—college students, accountants, writers, scientists, and others—who have become interested in memory training and memory competitions, such as the World Memory Championships. Ordinary people they may be, but extraordinary brains they must have . . . right?

Not necessarily. According to eight-time World Memory Champion Dominic O’Brien, most anyone can acquire an exceptional memory. When O’Brien first began to train his memory at age 30, he could remember no more than 6 or 7 playing cards in a row. Eventually, he was able to memorize 2,808 cards (54 decks) after looking at each card only once. “I transformed my memory power very quickly as a result of applying simple techniques and practicing regularly,” Dominic says. “If I can become a memory champion then anybody can” (D. O’Brien, personal communication, December 4, 2015). Just like a gymnast or wrestler, a memory athlete prepares, trains, and practices. A powerful memory takes work!

THE BRAINS OF MEMORY EXPERTS Researchers comparing a small sample of memory competitors to “normal” people found nothing extraordinary about their intelligence or brain structure. What they did find was heightened activity in specific brain areas, particularly in regions used for “spatial memory” (Maguire, Valentine, Wilding, & Kapur, 2003). This activity seems to be associated with the use of a strategy in which items to be remembered are placed along points of an imagined “journey” (Mallow, Bernarding, Luchtmann, Bethmann, & Brechmann, 2015). As it turns out, memory athletes rely heavily on this type of imagined journey, which is rich with visual images (Mallow et al., 2015; Martin, 2013). We will learn about this memory aid later in the chapter, when we discuss memory improvement, but first let’s get a grasp of how memories are processed.

Levels of Processing

One way to conceptualize memory is from a processing standpoint. To what degree does information entering the memory system get worked on? According to the levels of processing framework, there is a “hierarchy of processing stages” corresponding to different depths of information processing (Craik & Lockhart, 1972). Thus, processing can occur along a continuum from shallow to deep (Figure 6.1 on page 238). Shallow-level processing is primarily concerned with physical features (structural), such as the brightness or shape of an object, or the number of letters in a word, and generally results in short-lived memories. Deeper-level processing relies on characteristics related to patterns, like rhymes (phonemic) and meaning (semantic), and generally results in longer-lasting and easier-to-retrieve memories. So when you give little attention to data entering your sensory system, shallow processing occurs, resulting in more transient memories. If you really contemplate incoming information and relate it to memories you already have, deeper processing occurs, and the new memories are more likely to persist (Craik & Tulving, 1975; Francis & Gutiérrez, 2012; Newell & Andrews, 2004).
Suppose you are trying to remember the names of the three processes involved in memory: encoding, storage, and retrieval. You could try to memorize the words based on a shallow, structural characteristic (storage has seven letters, encoding has eight letters, and retrieval has nine letters), or you could think about the words on a deeper level, connecting them to concepts already stored in your memory system. Memory champion Dominic O’Brien came up with this one: Encoding makes him think of codes and secret agents, so he imagines a James Bond character going into a huge warehouse (storage facility) and seeing a golden retriever (retrieval) run out the door (D. O’Brien, personal communication, December 4, 2015). The more deeply you think about incoming information, considering its meaning or personal relevance, the greater success you will have learning and remembering it.

Fergus Craik and Endel Tulving explored levels of processing in their classic 1975 study. After presenting college students with various words, the researchers asked them yes or no questions, prompting them to think about and encode the words at three different levels: shallow, intermediate, and deep. The shallow questions required the students to study the appearance of the word: “Is the word in capital letters?” The intermediate-level questions related to the sound of the word: “Does the word rhyme with ‘weight’?” And finally, the deep questions challenged students to consider the word’s meaning: “Is the word a type of fish?” When the researchers surprised the students with a test to see which words they remembered without any cues or clues, the students were best able to recall words whose meaning they had thought about (Craik & Tulving, 1975). The take-home message: Deep thinking helps create stronger memories (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; Foos & Goolkasian, 2008).

Most people have the greatest success with (3) deep processing, but it depends somewhat on how they are prompted to retrieve information. For example, if someone asks you to remember any words that rhyme with “dive daring,” the name “Clive Wearing” will probably pop into your head regardless of whether you used deep processing.

The levels of processing model helps us understand why testing, which often requires you to connect new and old information, can improve memory and help you succeed in school. Research strongly supports the idea that “testing improves learning,” as long as the stakes are low (Dunlosky et al., 2013). The Show What You Know and Test Prep resources in this textbook are designed with this in mind. Repeated testing, or the testing effect, results in a variety of benefits: better information retention; identification of areas needing more study; and increased self-motivated studying (Roediger, Putnam, & Smith, 2011). Speaking of testing, why not take a moment and show what you know?

**FIGURE 6.1**

The Levels of Processing Framework of Memory

Information can be processed along a continuum from shallow to deep, affecting the probability of recall. Shallow processing, in which only certain details like the physical appearance of a word might be noticed, results in brief memories that may not be recalled later. We are better able to recall information we process at a deep level, thinking about meaning and tying it to memories we already have.

Goldfish: Gunnar Pippel/Shutterstock.
Flow With It: Stages of Memory

Psychologists use several models to explain how the memory system is organized. Among the most influential is the information-processing model first developed by Richard Atkinson and Richard Shiffrin. This model conceptualizes memory as a flow of information through a series of stages: sensory memory, short-term memory, and long-term memory (Figure 6.2) (Anderson, 1971; Atkinson & Shiffrin, 1968, January 31; Wood & Pennington, 1973).

The Information-Processing Model

According to the information-processing model, each stage of memory has a certain type of storage with distinct capabilities: sensory memory can hold vast amounts of sensory stimuli for a sliver of time, short-term memory can temporarily maintain and process limited information for longer periods (about 30 seconds, if there are no distractions), and long-term memory has essentially unlimited capacity and can hold onto information indefinitely. In the sections that follow, we will flesh out these concepts of sensory, short-term, and long-term memory, which are incorporated in most memory models.

The information-processing model is a valuable tool for learning about and researching memory, but like any scientific model, it has flaws. Some critics contend that sensory memory is really a primary component of perception. Others doubt that a clear boundary exists between short-term and long-term memory (Baddeley, 1995). Still others argue that this "pipeline" model is a simplistic representation because information does not necessarily flow through the memory system in a straight-line path (Cowan, 1988). Despite its weaknesses, the information-processing model remains an essential tool for explaining how memory works. As you read about Clive Wearing in the pages to come, you will see how both his short- and long-term memory are severely impaired.

CONNECTIONS

In Chapter 3, we defined sensation as the process by which receptors receive and detect stimuli. Perception is the process through which sensory information is organized, interpreted, and transformed into something meaningful. Some critics of the information-processing model suggest that sensory memory is an important component of perception, not a stage of memory.
Sensory Memory: The Here and Now

Think of all the information streaming through your sensory channels at this very moment. Your eyes may be focused on this sentence, but you are also collecting data through your peripheral vision. You may be hearing noises (voices in the distance), smelling odors (the scent of lotion or deodorant you applied earlier today), tasting foods (if you are snacking), and even feeling things (shoes gently squeezing your feet). Many of these sensory stimuli never catch your attention, but some are being registered in your sensory memory, the first stage of the information-processing model. The bulk of information entering sensory memory comes and goes like images flitting by in a movie. A few things catch your attention—the beautiful eyes of Zoe Saldana, the sound of her voice, and perhaps the color of her shirt—but not much more before the frame switches and you’re looking at another image. Information floods our sensory memory through multiple channels—what we see enters through one channel, what we taste through another, and so on.

ICONIC MEMORY: “MORE IS SEEN THAN CAN BE REMEMBERED” Interested in understanding how the brain processes data entering the visual channel, Harvard graduate student George Sperling (1960) designed an experiment to determine how much information can be detected in a brief exposure to visual stimuli. Sperling set up a screen that flashed multiple rows of letters for one-twentieth of a second, and then asked participants to report what they saw. His first goal was to determine how many letters the participants could remember when an array of letters (for example, three rows of four letters) was flashed briefly; he found that, on average, the participants only reported four letters. But Sperling wasn’t sure what this meant: Could the participants only store one row at a time, or did they store all the rows in their memory, but just not long enough to recite them before they were forgotten?

Sperling suspected that "more is seen than can be remembered" (1960, p. 1), so he devised a clever method called partial report to provide evidence. As with the original experiment, he briefly flashed an array of letters (for example, three rows of four letters), with all rows visible. But instead of having the participants report what they remembered from all the rows, he asked them to report what they remembered from just one row at a time (Figure 6.3).

Here’s how the study went: The array of letters was flashed, and once it disappeared, a tone was sounded. When participants heard a high-pitched tone, they were to report the letters in the top row; with a medium-pitched tone, the letters in the middle row; and with a low-pitched tone, the letters in the bottom row. The participants were only...
asked to give a partial report, that is, to report on just one of the rows, but they did not
know which row ahead of time. In this version of the study, the participants doubled
their performance, recalling approximately 76% of the letters regardless of which row
they were asked to recall (Sperling, 1960). Sperling’s research suggests that the visual
impressions in our sensory memory, also known as iconic memory, are photograph-like
in their accuracy but dissolve in less than a second. Given the short duration of iconic
memory, can you predict what would happen to the participants’ performance if there
were a delay before they reported what they saw?

**EIDETIC IMAGERY** Perhaps you have heard friends talk about someone who claims to have a “photographic memory” that can record and store images with the accuracy of a camera: “My cousin Dexter can look at a textbook page, remember exactly what it says in a few seconds, and then recall the information days later, seeing the pages exactly as they were.” That may be what Dexter claims, but is there scientific evidence to back up such an assertion? Not at this time (Gordon, 2012, December 19; MacLeod, Jonker, & James, 2013).

According to some reports, though, researchers have documented a phenomenon that comes fairly close to photographic memory. It’s called *eidetic imagery* (ahy-DET-ik), and the rare “handful” who have this ability can “see” an image or object sometimes long after it has been removed from sight, describing its parts with amazing specificity. For example, architect Stephen Wiltshire is an *autistic savant*, who reportedly can create detailed and accurate drawings of entire “cityscapes after a single helicopter ride” (Martin, 2013, p. R732). This ability seems to occur primarily in children, with some suggesting that this type of memory is lost as a child’s brain grows and develops (Ko, 2015; Searleman, 2007, March 12).

**ECCHOIC MEMORY** Exact copies of the sounds we hear linger longer than visual impressions; *echoic memory* (eh-KOH-ik) can last from about 1 to 10 seconds (Lu, Williamson, & Kaufman, 1992; Peterson, Meagher, & Ellsbur, 1970), and it can capture very subtle changes in sound. Research has shown that the introduction of a *single tone* played for 300 milliseconds initiates changes in brain activity (Inui et al., 2010). Even if you are not aware of it, your auditory system is picking up slight changes in stimuli and storing them in echoic memory for a brief moment. In this way, you don’t have to pay attention to every incoming sound. Perhaps you have had the following experience: During class, your instructor notices a classmate daydreaming and tries to bring her back to reality: “Olivia, could you please restate the question for us?” Her mind was indeed wandering, but amazingly she can recall the instructor’s last sentence, responding, “You asked us if brain scans should be allowed as evidence in courtrooms.” For this, Olivia can thank her echoic memory.

Although brief, sensory memory is critical to the creation of memories. Without it, how would information enter the memory system in the first place? The bulk of research has focused on iconic and echoic memories, which register sights and sounds, but memories can also be rich in smells, tastes, and touch. Data received from all of the senses are held momentarily in sensory memory. Yet at any given moment, you can only concentrate on a tiny percentage of the data flooding your sensory memory, and most of this information disappears quickly. Items that capture your attention can move into the next stage of information-processing: short-term memory.
Short-Term Memory: It Doesn’t Last Long

**LO 5** Summarize short-term memory.

When information enters your sensory memory, it does not linger. So where does it go next? If not lost in the overwhelming array of sensory stimuli, the data proceed to short-term memory, the second stage in the information-processing model proposed by Atkinson and Shiffrin (1968). The amount of time information is maintained and processed in short-term memory depends on how much you are distracted by other cognitive activities, but the duration can be about 30 seconds (Atkinson & Shiffrin, 1968). You can stretch short-term memory further with maintenance rehearsal, a technique of repeating what you want to remember over and over in your mind. Using maintenance rehearsal, you can theoretically hold onto information as long as you desire. This strategy comes in handy when you need to remember a series of numbers or letters (for example, phone numbers or zip codes). Imagine the following: While strolling down the street, you witness a hit-and-run accident. A truck runs a red light, smashes into a car, and then speeds away. As the truck zooms off, you manage to catch a glimpse of the license plate number, but how will you remember it long enough before reaching the 911 operator? If you’re like most people, you will say the plate number to yourself over and over, either aloud or in your mind, using maintenance rehearsal.

But maintenance rehearsal does not work so well if you are distracted. In a classic study examining the duration of short-term memory, most participants were unable to recall three-letter combinations beyond 18 seconds while performing another task (Peterson & Peterson, 1959; **Figure 6.4**). The task (counting backward by 3s) interfered with their natural inclination to mentally repeat the letter combinations; in other words, they were limited in their ability to use maintenance rehearsal. What this study reveals is that short-term memory has a limited capacity. Please remember this if you are tempted to text during class or watch TV while studying; if your goal is to remember what you should be concentrating on, you need to give it your full attention.

**CONNECTIONS**

Here, we see how memory is related to attention. In Chapter 4, we discussed the limited capacity of human attention. At any given point in time, there are only so many items you can attend to and thus move into your memory system.

**Synonyms**

- Maintenance rehearsal: Technique of repeating information to be remembered, increasing the length of time it can be held in short-term memory.
- Chunking: Grouping numbers, letters, or other items into meaningful subsets as a strategy for increasing the quantity of information that can be maintained in short-term memory.
- Working memory: The active processing of information in short-term memory; the maintenance and manipulation of information in the memory system.

**FIGURE 6.4**

**Duration of Short-Term Memory**

Distraction can reduce the amount of time information remains in short-term memory. When performing a distracting cognitive task, most people were unable to recall a letter combination beyond 18 seconds. Information from Peterson and Peterson (1959), Figure 1, p. 195.

**Short-Term Memory: It Doesn’t Last Long**

With maintenance rehearsal, you try to remember numbers and letters, for example, by repeating them over and over in your mind. But how many items can we realistically hold in our short-term memory at one time? Using a task called the Digit Span Test (**Figure 6.5**), cognitive psychologist George Miller (1956) determined that most people can retain only five to nine digits: He called this the “magical number seven, plus or minus two.” Indeed, researchers following up on this discovery have found that most people can only attend to about five to nine items at one time (Cowan, Chen, & Roudor, 2004; Cowan, Nugent, & Elliott, 2000). But what exactly constitutes an item? Must it be a single-digit number? Not necessarily; we can expand short-term memory by packing more information into the items to be remembered.

Consider this example: Your friend has just gotten a new phone number, which she rattle:s off as the elevator door closes between you. How are you going to remember her number long enough to create a new entry in your cell phone? You could try memorizing all 10 digits in a row (893550172), but a better strategy is to break the number into more manageable pieces (893-555-0172). Here, you are using chunking, Miller’s (1956) name for grouping numbers, letters, or other types of information into meaningful “chunks,” or units of information (Cowan, 2015). Can you think of situations in which you might chunk information to help you remember it more easily?

Short-term memory can only hold so much, but we can expand its storage capacity by chunking. The fact that short-term memory is actively processing information and is flexible in this regard suggests that it may be more than just a stage in which
information is briefly stored. Indeed, many psychologists believe that short-term memory is hard at work.

**Working Memory: Where the Action Is**

LO 7 Describe working memory and its relationship to short-term memory.

Updated versions of the information-processing model include a concept known as working memory (Baddeley, 2012; Baddeley & Hitch, 1974), which refers to what is going on in short-term memory. Working memory is the active processing through which we maintain and manipulate information in the memory system. Let’s use an analogy of a “bakery” and what goes on inside it. Short-term memory is the bakery, that is, the place that hosts your current thoughts and whatever your brain is working on at this very moment. Working memory is what’s going on inside the bakery—making bread, cakes, and pastries. Some psychologists use the terms short-term and working memory interchangeably. For our purposes, we will identify “short-term memory” as a stage in the original information-processing model as well as the “location” where information is temporarily held, and “working memory” as the activities and processing occurring within.

According to the model of working memory originally proposed by psychologists Alan Baddeley and Graham Hitch (1974; Baddeley, 2012), the purpose of working memory is to actively maintain information, and thus enable complex cognitive tasks. To accomplish this, working memory has four components: the phonological loop, visuospatial sketchpad, central executive, and episodic buffer (Baddeley, 2002; FIGURE 6.6).

**FIGURE 6.5 Digit Span Test**
The Digit Span Test is a simple way to assess memory. Participants are asked to listen to a string of numbers and then repeat them. The string of numbers grows longer as the test progresses. Ask a friend to give you this test and see how many numbers you can remember. For a real challenge, you can even try to recite the list backward!

**FIGURE 6.6 Working Memory**
Working memory represents the active processing occurring in short-term memory. Overseeing the big picture is the central executive, which directs attention and integrates processing among three subsystems: the phonological loop, visuospatial sketchpad, and episodic buffer. To see how this model works, imagine you have stopped by the supermarket to pick up groceries. You rehearse the shopping list with your phonological loop, produce a mental layout of the store with your visuospatial sketchpad, and use the episodic buffer to access long-term memories and determine whether you need any additional items. Tying together all these activities is the central executive. Information from Baddeley (2002).
PHONOLOGICAL LOOP  The phonological loop is responsible for working with verbal information for brief periods of time; when exposed to verbal stimuli, we “hear” an immediate corollary in our mind. This component of working memory is what we use, for example, when we are reading, trying to solve problems, or learning new vocabulary.

VISUOSPATIAL SKETCHPAD  The visuospatial sketchpad is where visual and spatial data are briefly stored and manipulated, including information about your surroundings and where things are in relation to each other and you. This working memory component allows you to close your eyes and reach for the coffee mug you just set down. We can also use information from long-term memory in our visuospatial sketchpad (Baddeley, 1999, 2006).

CENTRAL EXECUTIVE  The central executive has responsibilities similar to those of the chief executive in any organization—it directs attention, makes plans, and coordinates activities (Baddeley, 2002). Part of its role is to determine what information is important, and to help organize and manipulate consciousness. Why is it that we cannot actually text, eat, and safely drive all at once? Like a juggler, the central executive can only catch and toss one ball at a time. We may think we are doing all three tasks at once, but we are really just swapping the alternatives in and out at a fast pace.

EPISODIC BUFFER  The episodic buffer is the part of working memory where information from the phonological loop, visuospatial sketchpad, and long-term memory can be brought together temporarily, under the direction of the central executive (Baddeley, 2000). The episodic buffer forms the bridge between memory and conscious awareness. It enables us to assign meaning to past events, solve problems, and make plans for the future.

LET’S WORK IT OUT  Imagine you are trying to buy some running sneakers online. You need your password, so you retrieve it from long-term memory and then “hear” the ten letters and numbers played in your phonological loop. Now you need your credit card, so you think back to the last place you saw it—the kitchen counter—and bring forth a mental image of how your kitchen is laid out in your visuospatial sketchpad. The episodic buffer allows memories of your password and credit card location to come into your awareness, and then fade away. All the while, the central executive is directing your attention from one place to the next, enabling you to complete every step of the purchase.

SOCIAL MEDIA AND PSYCHOLOGY  Multitasking and Memory

It’s Sunday evening, and you need to catch up on the reading for your psychology class. You sit down in a quiet place and open your textbook. But just as you are getting into the psychology groove, you feel a vibration inside your pocket—your cell phone. Could it be a text, a new Snapchat video, a reply to your latest tweet? You can’t resist checking. You return to your studies, but social media notifications continue to occur every 5 or 10 minutes, pulling your attention away from psychology. By the evening’s end, you do manage to get through the assignment, but how have all these digital distractions affected your memory of the material? Definitely not for the better.

Various studies have linked media multitasking with diminished academic performance (Junco, 2015; Karpinski, Kirschner, Ozer, Melott, & Ochwo, 2013). One group of researchers found that college students who frequently text and use Facebook while studying have lower grade point averages (GPA) than those who do not (Junco & Cotten, 2012). Another research team found that teenagers who commonly
multitask with media perform worse on math and English achievement tests than those
who multitask less (Cain, Leonard, Gabrieli, & Finn, 2016). Many of these studies are
corrrelational, making it difficult to untangle cause-and-effect relationships. Does media
multitasking make it harder to remember material and thus lead to inferior academic
performance, or do lower-achieving students simply have a more difficult time resisting
the lure of Twitter, Snapchat, and Instagram? Perhaps students with lower GPAs spend
more time on social media (Michikyan, Subrahmanyam, & Dennis, 2015).

Controlled experiments do suggest that digital distractions have the potential to
impair memory and learning. In one study, researchers had university students sit
through lectures and then quizzed them on their memory of the material. Students
who had used instant messaging (IM) or Facebook during the lecture performed
worse than those who had taken notes with a pencil and paper (Wood et al., 2011).
Their diminished performance may have to do with the burden that social media
imposes on working memory. Reading a funny post or responding to a message re-
quires a shift in attention—hard work for the brain, which has to engage and disen-
gage different networks (Courage, Bakhtiar, Fitzpatrick, Kenny, & Brandeau, 2015;
de Fockert, 2013; Junco, 2015). What does this mean for you? If you’re multitasking
with media, you are likely missing important information from lectures and readings.
One of the most remarkable findings from a recent study might come as a surprise to
you: Even when students use their laptops only for note-taking, they perform more
poorly on conceptual questions than students who take notes by longhand (Mueller
& Oppenheimer, 2014).

**In Class: Collaborate and Report**

Find a partner and complete the following memory task:

A) Choose an activity that
requires your attention (for example, texting each other the names of your favorite TV
show characters; taking turns naming books you have read). B) As you perform this task,
try to memorize the 40 key terms listed at the end of the chapter. C) After 5 minutes,
close your textbook and write the key terms (in order) on a blank sheet of paper.
D) Discuss how multitasking affected your maintenance rehearsal of the key terms.

As you know, short-term memory is limited in its capacity and duration, and work-
ing memory has its limitations as well. So how do we maintain so much information
over the years? What aspect of memory makes it possible to memorize thousands of
vocabulary words, scores of names and facts, and lyrics to your favorite songs? Enter
long-term memory.

**Long-Term Memory: Save It for Later**

Items that enter short-term memory have two possible fates: Either they fade away or
they move into long-term memory (figure 6.7 on page 246). Think of how much infor-
mation is stored in your long-term memory: funny jokes, important conversations,
images of faces, song lyrics, multiplication tables, and so many words—around 10,000
to 11,000 word families (such as “smile,” “smiled,” “smiling”) for English-speaking col-
lege students (Trefers-Daller & Milton, 2013). Could it be that long-term memory
has an endless holding capacity? It may be impossible to answer this question, but for
all practical purposes our long-term memory has no limits. Some memories stored
there, such as street names from your childhood, may even last a lifetime (Reber, 2010,
May/June; Schmidt, Pecck, Paas, & van Breukelen, 2000).

**LO 8 Describe long-term memory.**

Long-term memory can be described in a variety of ways, but psychologists often
distinguish between two categories: explicit and implicit. **Explicit memory** is the type
of memory you are aware of having and can consciously express in words or declare: **Roses are red, guacamole is made with avocados; I wore faded jeans yesterday.** **Implicit memory** is a memory of something you know or know how to do, which may be automatic, unconscious, and difficult to bring to awareness and express.

**EXPLICIT MEMORY** Endel Tulving (1972) proposes there are two forms of explicit memory: semantic and episodic. **Semantic memory** pertains to general facts about the world (the Earth is located in the Milky Way; the United States holds presidential elections every four years; the brain has two hemispheres). But there is also a type of memory you can call your own. Your first experience riding a bike, the time you got lost in the supermarket, the sandwich you ate yesterday—all of these personal memories are part of your **episodic memory** (ep-uh-SOD-ik). You can think of episodic memory as the record of memorable experiences, or “episodes,” in your life, including when and where they occurred (Tulving, 1985). One could say that semantic memories are verifiable, but episodic memories are not.

**FLASHBULB MEMORIES** Often, our most vivid episodic memories are associated with intense emotion. Think about an emotionally charged experience from your past: learning about a terrorist attack, getting news that someone you love has been in an accident, or hearing that your favorite sports team has won a historic championship. If recollecting these moments feels like watching a 4-D movie, you might be experiencing what psychologists call a **flashbulb memory**, a detailed account of circumstances surrounding an emotionally significant or shocking, sometimes historic, event (Brown & Kulik, 1977). With flashbulb memories, you often recall the precise moment you learned of an event—where you were, who or what source relayed the news, how it made you feel, what you did next, and other random details about the experience (Brown & Kulik, 1977). Perhaps you have a flashbulb memory of hearing about the horrific shootings at Sandy Hook Elementary School in Newtown, Connecticut, in 2012, or learning that...
Donald Trump won the 2016 presidential election or the Chicago Cubs won the World Series; you recall whom you were with, what you were drinking and eating, what music was playing. Note that a flashbulb memory is a specific type of episodic memory of the experiences associated with learning about an event rather than “first-hand memories” of experiencing the event (Hirst & Phelps, 2016).

Because flashbulb memories seem so strong, vivid, and rich in detail, we often place great confidence in them, but research suggests that we should be cautious about doing this. Flashbulb memories sometimes include inaccuracies or lack specific details (Neisser, 1991; Hirst et al., 2015).

**IMPLICIT MEMORY** Unlike explicit memory, which can easily flow into conscious thought, implicit memory is difficult to bring into awareness and express. It is a memory for something you know or know how to do, but which might be automatic or unconscious. Many of the physical activities we take for granted, such as playing an instrument, driving a car, and dribbling a basketball, use a special type of implicit memory called procedural memory, that is, the memory of how to carry out an activity without conscious control or attention. After his illness, Clive Wearing could still pick up a piece of music and play it on the piano. He had no recollection of learning to sight-read or play, yet he could execute these skills like the professional he had always been (Vennard, 2011, November 21). Therefore, Clive’s procedural memory was still working.

Memories acquired through classical conditioning are also implicit. Let’s say you enjoy eating food at McDonald’s and the very sight of the golden arches makes you salivate like one of Pavlov’s dogs. Somewhere along the line, you formed an association, a memory linking the appearance of that restaurant to juicy hamburgers and creamy shakes, but the association does not require your conscious awareness (Cowan, 1988). It is implicit.

**Improve Your Memory**

How does the process of moving data into the memory system create long-term memories? Some activities work well for keeping information in short-term memory (maintenance rehearsal, for example). Others involve moving information from short-term memory to long-term memory. Let’s take a look at some of these processes, kicking off our discussion with a little test.

**try this ↓**

Take 15 seconds and try to memorize these seven words in the order they appear:

**puppy stop sing sadness soccer kick panic**

Now close your eyes, and see how many you recall. How did you do?

You just completed a miniversion of “Random Words,” an event in the World Memory Championships. One memory champion memorized 300 words in 15 minutes. What is the secret? Many memory athletes use mnemonic (nih-MON-ik) devices—techniques for improving memory. You have probably used several mnemonic devices in your own life. For example, have you ever relied on the first-letter technique to remember the order of operations in math (Please Excuse My Dear Aunt Sally)? Or perhaps you have used an *acronym*, such as ROY G BIV, to remember the colors of the rainbow (*FIGURE 6.8* on page 248)? Chunking, which we discussed earlier, is also a mnemonic technique. As you can see in *INFOGRAPHIC 6.1* (page 251), mnemonic devices and other memory strategies can enhance the retention of material as you study.

**METHOD OF LOCI** One of the mnemonics memory athletes rely on most is the method of loci (LOH-sahy, meaning “places”). Here’s how it works: When presented with a series
of words to remember, the competitors take the words on a mental journey through a place they know well. For example, memory expert Dorothea Seitz goes on a mental journey through her bedroom and bathroom. Walking through her room, she puts the items-to-be-remembered at predetermined spots along the way. Let’s say she is trying to remember the seven words from the Try This exercise on the previous page. Dorothea visualizes herself entering her bedroom. The first thing she comes upon is the bed, so she might imagine a cute puppy playing with the pillow. Then she encounters a bedside table, which suddenly becomes a bus stop with a bus parked in front. She walks over to the sofa, climbs up onto it, and begins to sing. The next object on her path is a box, but not an ordinary box, because it’s weeping tears of sadness. Next in her path is a mirror that she shatters to pieces with a soccer ball. When she gets to the sink, she kicks it with her foot. Finally, she imagines aliens climbing out of the toilet, causing her to panic.

If she needs to remember the items, she retraces the journey, stopping at each point to observe the image she left there (D. Seitz, personal communication, December 13, 2009).

You can use the method of loci, too. Just pick a familiar route—through your favorite restaurant, college campus, even your body parts—and mentally place things you need to remember at points along the way. For remembering short lists, memory champion Dominic O’Brien suggests tagging items to pre-established points along the body (O’Brien, 2013). Suppose you need to pick up five items at the grocery: milk, eggs, olive oil, bananas, and cherries. Choose some body parts and then visually connect them to the items you need. For example, your hair is slicked back in olive oil; your nose is a big long banana; you can’t see because someone threw eggs in your eyes; cherries dangle from your ears like earrings; and you have a milk mustache. The method of loci works very well for memorizing lists, especially if you practice often.

Hierarchical Structures Another way to boost your memory is to arrange the material you are trying to memorize into a hierarchy, or a system of meaningful categories and subcategories. In one classic study, researchers found that if participants were given a list of words that followed a hierarchical structure, they were better able to recall the words than a similar group of participants who were asked to memorize the same words that had not been organized in any meaningful way. In fact, the participants who had learned the words using the hierarchy were able to recall three times as many words as the other group (Bower, Clark, Lesgold, & Winzenz, 1969).
AUTOMATIC AND EFFORTFUL PROCESSING  As you recall from earlier in the chapter, the levels of processing framework suggests that stronger memories result when you think about information on a deep level. Memory experts come to the championships ready to use effortful processing. As the name implies, effortful processing is not only intentional but also requires “cognitive effort,” which broadly refers to the “degree of engagement with demanding tasks” (Westbrook & Braver, 2015, p. 396). In other words, how much you are willing to buckle down and put your mind to a task. Some types of effortful processing, such as maintenance rehearsal, are useful for extending the amount of time you can hold onto information in short-term memory. Others employ patterns and meaning to encode information for longer storage. As mentioned earlier, one expert links hundreds of elaborate images (like the puppy playing on the pillow, or aliens rising out of the toilet) on a mental journey—not an easy task to perform in 15 minutes. Her effortful processing occurs at a deep level and, as the levels of processing framework suggests, results in more successful learning and retention of information.

Your decisions to use (or not use) effortful processing may impact your academic achievement, performance on standardized tests, and ability to solve everyday problems. But despite your best intentions, you may not always choose the effortful path, particularly if the “cost” is too high and the effort feels “aversive” (Westbrook & Braver, 2015). For example, your psychology writing assignment is so cognitively taxing that you decide it’s not worth the effort; you’d rather spend your time creating a new photo album on Facebook. Even deciding whether to use effortful processing takes effort, putting a strain on working memory, which has limited resources (Boureau, Sokol-Hessner, & Daw, 2015). What can a student do to make effortful processing less daunting and concentrating easier? Here are a few things that may help: Work in a quiet room, keep cell phones and TVs out of sight, sit at the front of the classroom, and keep your eye on a clock so you can use your time wisely (Duckworth, Gendler, & Gross, 2016).

We should note that some encoding occurs through automatic processing—that is, with little or no conscious effort or awareness (Evans & Stanovich, 2013; Hasher & Zacks, 1979). For example, if you walked into the conference room at the World Memory Championships, you might process all sorts of information without even trying—like the fact that most of the people milling around the room are men, and that some teams wear matching outfits. You would not make an effort to pick up on these details, but you remember them nevertheless. Your memory system absorbs the data automatically.

ELABORATIVE REHEARSAL AND VISUALIZATION  Effortful processing is evident in elaborative rehearsal, the method of connecting incoming information to knowledge in long-term memory. Here, we can see that the level of processing occurs at a deep level, which suggests the encoding of information will be more successful. The memory champions’ mental walks involve this type of deeper processing (elaborative rehearsal) because they take new information and put it in the familiar framework of places they know. By picturing the journey and the objects-to-be-remembered in their minds’ eye, they take advantage of visualization, another effective encoding strategy. People tend to remember verbal information better when it’s accompanied by vivid imagery. Some research suggests, for example, that children recall news stories better when they see them presented on television, as opposed to reading about them in a printed article (Walma van der Molen & van der Voort, 2000).

DISTRIBUTED PRACTICE  What other learning strategies might improve encoding and help you move information into long-term memory? You’ve probably heard this before, but you should avoid cramming when trying to learn new material.
Psychologists don’t call it cramming, though; instead, we refer to it as **massed practice**, meaning that learning sessions occur generally within the same day, “back-to-back or in relatively close succession” (Dunlosky et al., 2013, p. 36). The other approach to learning uses **distributed practice** by spreading study sessions over the course of many days. Research starting as early as the 1800s resoundingly shows that distributed practice is much more effective for learning material than cramming sessions at the last minute (Dunlosky et al., 2013; Ebbinghaus, 1885/1913; Rohrer & Taylor, 2006). When researchers asked students to learn a new mathematical skill, they found that participants who practiced the new skill in two sessions (separated by a week) did better on a practice test (4 weeks later) than those who spent the same amount of time practicing in one session (Pashler, Rohrer, Cepeda, & Carpenter, 2007). Similarly, students who reviewed material from a natural science class 8 days after the original lectures did better on final exams than students who reviewed the material 1 day after the lectures (Kapler, Weston, & Wiseheart, 2015).

**In Class: Collaborate and Report**

In your groups, **A)** discuss your daily routines. **B)** Create a weekly calendar showing when you study and how much time you devote to each study session. **C)** Determine whether you are using distributed practice.

**SLEEP AND MEMORY**

In Chapter 4, we discussed how sleep and dreams relate to memory. For example, researchers suspect that sleep spindles are associated with memory consolidation, and some theorists emphasize the importance of REM sleep in this process.

**SYNONYMS**

**massed practice**  
Studying for long periods of time without breaks.

**distributed practice**  
Spreading out study sessions over time with breaks in between.

**TABLE 6.1  SLEEP AND MEMORY**

<table>
<thead>
<tr>
<th>Sleep</th>
<th>Impact on Memory</th>
</tr>
</thead>
</table>
| Get Adequate Sleep  
Get sleep before you learn something new. | Readies brain for “initial formation of memories” (Contie, Defibaugh, Steinberg, & Wein, 2013, April). |
| Get sleep after you learn something new. | Sleeping increases potential for retention of newly acquired information. Saves and strengthens information in the brain, which means you will be more likely to remember what you learned (Contie et al., 2013, April). |
| Impact of Sleep Deprivation  
Sleep deprivation associated with increased risk for heart disease, stroke, and type 2 diabetes (LeWine, 2014, May 2). | These diseases can decrease blood flow, preventing cells from receiving oxygen and glucose, which can affect proper brain function (LeWine, 2014, May 2). |
| Staying up all night can interfere with learning. | May reduce ability to learn new information by 40% (Contie et al., 2013, April). |
| Impact of Sleep on Emotions  
Sleep can increase durability of memories for fear-laden events. | Sleep “strengthens fear memories.” Conditioned fear memories are consolidated while we sleep, helping us to distinguish between what is threatening and what is not (Goldstein & Walker, 2014). |
| Sleep can reduce the strength of emotional reactions to events. | REM sleep helps to reduce or dampen emotional reactions to events, while still consolidating memories (Goldstein & Walker, 2014). |

Get 7–8 hours of sleep every night; too much (over 9 or 10 hours) and too little (less than 5 hours) impact cognitive activity. In general, sleep helps sustain memory in “later life” (LeWine, 2014, May 2; Devore et al., 2014).

Psychologists don’t call it cramming, though; instead, we refer to it as **massed practice**, meaning that learning sessions occur generally within the same day, “back-to-back or in relatively close succession” (Dunlosky et al., 2013, p. 36). The other approach to learning uses **distributed practice** by spreading study sessions over the course of many days. Research starting as early as the 1800s resoundingly shows that distributed practice is much more effective for learning material than cramming sessions at the last minute (Dunlosky et al., 2013; Ebbinghaus, 1885/1913; Rohrer & Taylor, 2006). When researchers asked students to learn a new mathematical skill, they found that participants who practiced the new skill in two sessions (separated by a week) did better on a practice test (4 weeks later) than those who spent the same amount of time practicing in one session (Pashler, Rohrer, Cepeda, & Carpenter, 2007). Similarly, students who reviewed material from a natural science class 8 days after the original lectures did better on final exams than students who reviewed the material 1 day after the lectures (Kapler, Weston, & Wiseheart, 2015).
Study Smarter: Methods of Improving Your Memory

You may never need to memorize the order of 2,808 playing cards as memory champion Dominic O’Brien did. But you do need to be able to understand and recall hundreds of details when your teacher hands you an exam. Luckily, research shows that certain strategies and memory techniques will help you retain information when you study.

**Acronyms and first-letter technique**
It’s easier to remember a short phrase than a string of information.

**Method of loci**
It’s easier to remember information when you deliberately link it to locations along a familiar route.

**Chunking**
It’s easier to remember a few chunks than a long string.

**Elaborative rehearsal**
Elaborative rehearsal is deep processing that boosts transfer to long-term memory by connecting new information to older memories.

**Hierarchical structures**
Hierarchical structures organize information into a meaningful system. The process of organizing aids encoding and, once encoded, the information is easier to recall.

**Mnemonics**
Mnemonics translate information into a more easily remembered form.

**Distributed practice**
Distributed practice creates better memory than study crammed into a single session.

**Make connections**
Elaborative rehearsal is deep processing that boosts transfer to long-term memory by connecting new information to older memories.

**Hierarchical structures**
Hierarchical structures organize information into a meaningful system. The process of organizing aids encoding and, once encoded, the information is easier to recall.

**Mnemonics**
Mnemonics translate information into a more easily remembered form.
can be of benefit. In one study, participants who experienced a 15-minute period of wakeful resting (sitting in a dark quiet room) displayed better retention of newly learned material than those who played a game for 15 minutes. Wakeful resting seems to allow newly learned material to be encoded better, and thus retained in memory longer (Dewar, Alber, Butler, Cowan, & Della Sala, 2012). What might this mean for you? Make sure you allow yourself some quiet time following the learning of new material. Of course, it takes more than good rest to succeed in college; you need to be able to analyze, apply, and synthesize material, not just remember it.

“Wow, that’s a lot to remember,” you may be saying. Hopefully, you can retain it with the help of some of the mnemonic devices we have presented. You might also take a wakeful resting break in preparation for the next section, which focuses on the topic of memory retrieval.

**In Class: Collaborate and Report**

In your group, describe three strategies you could use to memorize the list of key terms at the end of this chapter. (Hint: Refer to the section “Improve Your Memory.”)

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**show what you know**

1. According to the information-processing model, our short-term memory can hold onto information for up to about __________ if we are not distracted by something else.
   a. 10 seconds  
   b. 30 seconds  
   c. 45 seconds  
   d. 60 seconds

2. As you enter the airport, you try to remember the location of the baggage claim area. You remember the last time you picked up your friend at this airport, and using your visuospatial sketchpad, realize the area is to your left. This ability demonstrates the use of your:
   a. sensory memory.  
   b. working memory.  
   c. phonological loop.  
   d. flashbulb memory.

3. If you are trying to memorize a long password, you could use __________, by grouping the numbers and symbols into meaningful units of information.

4. Develop a mnemonic device to help you memorize the following terms from this section: sensory memory, long-term memory, explicit memory, semantic memory, episodic memory, flashbulb memory, implicit memory, and procedural memory.

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**Retrieval and Forgetting**

Have you ever heard the saying “An elephant never forgets”? Granted, this might be somewhat of an overstatement, but as far as animals go, elephants do have remarkable memories. Consider the story of two elephants that briefly worked together in the circus and then were separated for 23 years. When they re-encountered one another at an elephant sanctuary in Tennessee, the two animals started to inspect each other’s trunk scars and “bellowed” in excitement: The long-lost friends had recognized one another (Ritchie, 2009, January 12)! An elephant’s memory—and yours, too—is only as good as its ability to retrieve stored memories. Let’s return to the World Memory Championships and examine the critical process of retrieval.

**What Can You Retrieve?**

Every event in the World Memory Championships begins with encoding data into the memory system and storing that information for later use. Contestants are presented with information—numbers, words, historic dates, and the like—and provided a certain amount of time to file it away in long-term memory. But no matter how much information they absorb, the contestants’ efforts are meaningless if they can’t retrieve it in the recall phase of the event.
RETRIEVAL CUES AND PRIMING One of the most grueling events in the World Memory Championships is “One Hour Numbers,” a race to see who can memorize the greatest number of random digits in an hour. Contestants are given four sheets of paper, each containing 1,000 random digits, and 1 hour to cram as many digits as possible into their long-term memories. During the recall phase that follows, they get 2 hours to scrawl the correctly ordered numbers on blank sheets of paper. This is a backbreaker because there are no reminders, or retrieval cues, to help contestants locate the information in their long-term memory. Retrieval cues are stimuli that help you retrieve stored information that is difficult to access (Tulving & Oder, 1968). For example, let’s say you were trying to remember the name of the researcher who created the working memory model introduced earlier in the chapter. If we gave you the first letter of his last name, B, would that help you retrieve the information? If your mind jumped to “Baddeley” (the correct answer), then B served as your retrieval cue. You probably create your own retrieval cues to memorize important information. When you take notes, for example, you don’t copy everything you are reading; you write down enough information (the cue) to help you later retrieve what you are trying to learn. Or you might name a photo file in your computer “JoseBday4” so you can remember that the photo was taken on Jose’s 4th birthday. Remember, “a good external cue can sustain memory retrieval in the face of considerable forgetting” (Tullis & Benjamin, 2015, p. 922).

Even Clive Wearing, who could not remember what was happening from one moment to the next, showed evidence of using retrieval cues. For instance, Clive spent 7 years of his life at St. Mary’s Hospital in Paddington, London, yet had no conscious memory of living there. And, according to his wife, Deborah, Clive was “completely devoid of knowledge of his own location; the hospital name was not at all connected with his sense of location (D. Wearing, personal communication, June 25, 2013). But if Deborah prompted him with the words “St. Mary’s,” he would chime back, “Paddington,” oblivious to its connection (Wearing, 2005, p. 188). In this instance, the retrieval cue in Clive’s environment (the sound of the word “St. Mary’s”) was priming his memory of the hospital name. Priming, a type of implicit memory, awakens memories with the help of retrieval cues.

At this point, you may be wondering how priming can occur in a person with severe amnesia. Clive’s conscious, explicit memory is diminished, but his unconscious, implicit memory still functions, evidenced by his response to priming. Just because he could not articulate, or “declare,” the name of the hospital does not mean that the previously known word combination had vanished from his memory system.

RECALL AND RECOGNITION Now let’s return to the “One Hour Numbers” event of the World Memory Championships. This type of challenge relies on pure recall, the process of retrieving information held in long-term memory without the help of explicit retrieval cues. Recall is what you depend on when you answer fill-in-the-blank or short-answer essay questions on exams. Say you are given the following prompt: “Using a computer metaphor, what are the three processes involved in memory?” In this situation, you must come up with the answer from scratch: “The three processes are encoding, storage, and retrieval.”

Now let’s say you are faced with a multiple-choice question: “One proven way to help you retain information is: (a) distributed practice, (b) massed practice, or (c) eidetic imagery.” Answering this question relies on recognition, the process of matching incoming data to information stored in long-term memory. Recognition is generally a lot easier than recall because the information is right before your eyes; you
just have to identify it (*Hey, I've seen that before*). Recall, on the other hand, requires you to come up with information on your own. Most of us find it easier to recognize the correct answer from a list of possible answers in a multiple-choice question than to recall the same correct answer for a fill-in-the-blank question.

**SERIAL POSITION EFFECT** Recall and recognition come into play outside of school as well. Just think about the last time someone asked you to pick up some items at the store. In order to find the requested goods, you had to recognize them (*There's the ketchup*), but even before that you had to recall them—a much harder task if they are not written down. The ability to recall items from a list depends on where they fall in the list, a phenomenon psychologists call the **serial position effect** (*Figure 6.9*). When given a list of words to memorize, research participants are better able to remember items at the beginning of the list, which is known as the **primacy effect**, as well as items at the end, which is called the **recency effect** (Deese & Kaufman, 1957; Kelley, Neath, & Surprenant, 2015; Murdock, 1962).

Imagine you are on your way to the store to buy supplies for a dinner party, but your cell phone battery is about to die. Your phone rings; it's your housemate asking you to pick up the following items: napkins, paper towels, dish soap, butter, laundry soap, paper plates, sparkling water, ice cream, plastic spoons, bread, pickles, and flowers. Without any way to write down this list, you are at the mercy of the serial position effect. In all likelihood (and if you don't use mnemonics), you will return home with napkins, paper towels, and a bottle of dish soap (due to the primacy effect), as well as bread, pickles, and flowers (due to the recency effect); the items in the middle will more likely be forgotten. Similarly, items are more "popular" when listed at the beginning or end of a menu, as opposed to the middle, presumably due to the serial position effect; they pop into your head more easily when you are ordering your meal (Bar-Hillel, 2015).

**MEMORY AND CULTURE** Research also suggests that culture plays a role in the types of recollections people have. Chinese people, for example, are more likely than Americans to remember social and historical occurrences and focus their memories on other people. Americans, on the other hand, tend to recall events as they relate to their individual actions and emotions (Wang & Conway, 2004). This may have something to do with the fact that China has a **collectivist** culture, whereas the United States is more **individualistic**. People in collectivist societies tend to prioritize the needs of family and community over those of the individual. Individualistic cultures are more “me” oriented, or focused on autonomy and independence. It thus makes sense that people from the collectivist culture of China would have more community-oriented memories than their American counterparts.

**The Encoding Specificity Principle**

When it comes to retrieving memories, context matters. Where were you when you encoded the information, and what was occurring around you? Researchers have found that environmental factors play a key role in determining how easily memories are retrieved.

**LO 9** Illustrate how encoding specificity relates to retrieval cues.

**CONTEXT IS EVERYTHING** In a classic study by Godden and Baddeley (1975), participants learned lists of words under two conditions: while underwater (using scuba gear) and on dry land. They were then tested for recall in both conditions: If they learned the list underwater, they were tested underwater and on dry ground; if they learned the list on dry ground, they were tested on dry ground and underwater. The participants were better able to retrieve words when the learning and recall
occurred in the same location (Figure 6.10). If they learned the words underwater, they had an easier time recalling them underwater. Words learned on land were easier to recall on land. Here, we have an example of context-dependent memory; memories are easier to access when the encoding and retrieval occur in similar contexts.

Context-dependent memory is part of a broader phenomenon conveyed by the encoding specificity principle, which states that memories are more easily recalled when the context and cues at the time of encoding are similar to those at the time of retrieval (Smith, Glenberg, & Bjork, 1978; Tulving & Thomson, 1973). There is even evidence that summoning a memory for an event reactivates the same brain areas that became excited during the event itself (Danker & Anderson, 2010). This suggests that the activity in your brain at the time of encoding is similar to that at retrieval, and researchers using fMRIs have found support for this (Gottfried, Smith, Rugg, & Dolan, 2004).

In Class: Collaborate and Report

Team up and discuss A) how the encoding specificity principle might help you remember people’s names; and B) how you might use the encoding specificity principle to improve your retention of course information.

IT ALL COMES FLOODING BACK In your own life, you may have noticed that old memories tend to emerge from the woodwork when you return to the places where they were created. Dining at a restaurant you once frequented with an ex-boyfriend or girlfriend probably sparks memories of romantic moments (or perhaps a bitter argument) you had there. Going to a high school reunion might bring back memories of football games, dances, and classrooms not recalled in years. How does returning to the birthplace of a memory help bring it to mind? Places where memories are created often abound with retrieval cues—sights, sounds, tastes, smells, and feelings present at the time of encoding. These retrieval cues help awaken stored memories.

Suppose you go to a friend’s house to watch the movie 50 First Dates starring Adam Sandler and Drew Barrymore. While encoding a memory of the movie, you are exposed to all sorts of stimuli in the environment, such as the hum of an air conditioner, the taste of the chips and salsa you are munching on, the tabby cat purring next to you on the sofa. All these stimuli have nothing to do with 50 First Dates, but they are strongly linked to your experience of watching the film. So the next time you are at your friend’s house and you see that tabby cat purring on the sofa, thoughts of “Ten Second Tom” might come back to you.

MOODS, INTERNAL STATES, AND MEMORY The encoding specificity principle does not merely apply to the context of the surroundings. Remembering things is also easier when physiological and psychological conditions, including moods and emotions,
are similar at the time of encoding and retrieval. Sometimes memories can be best retrieved under such circumstances; we call this state-dependent memory. One morning upon awakening, you spot a red cardinal on your window ledge. You forget about the cardinal for the rest of the day—even when you pass the very same window. But come tomorrow morning when you are once again half-awake and groggy, memories of the red bird return. Here, your ability to recall the cardinal is dependent on your internal or physiological state being the same as it was at the time of encoding. Retrieval is also easier when the content of a memory corresponds to our present emotional state, a phenomenon known as mood congruence (Bower, Gilligan, & Menteiro, 1981; Drace, Ric, & Desrichard, 2010). If you are in a happy mood, you are more likely to recollect a happy-go-lucky character from a book, but if you are in a sour mood, you are more inclined to remember the character whose bad mood matches yours.

### How Easily We Remember: Memory Savings

Retrieval is clearly at work in recall and recognition, the two processes we compared above. But there is another, less obvious form of retrieval that occurs in the process of relearning. Perhaps you’ve noticed that you learn material much more quickly a second time around. Math equations, vocabulary, and grammar rules seem to make more sense if you’ve been exposed to them before. Some information seems to stick better when we learn it twice (Storm, Bjork, & Bjork, 2008).

#### HERMANN EBBINGHAUS

The first person to quantify the effect of relearning was Hermann Ebbinghaus (1850–1909), a German psychologist and pioneering researcher of human memory. Ebbinghaus was the sole participant in his experiments, so his research actually shed light on his memory, although the trends he uncovered in himself seem to apply to human memory in general (Murre & Dros, 2014).

Thorough scientist that he was, Ebbinghaus spent hour upon hour, day after day memorizing lists of “nonsense syllables”—meaningless combinations of vowels and consonants such as DAZ and MIB. Once Ebbinghaus had successfully remembered a list, meaning he could recite it smoothly and confidently, he would put it aside. Later, he would memorize it all over again and calculate how much time he had saved in Round 2, a measure called the “savings score” (Ebbinghaus, 1885/1913). In a study that supports Ebbinghaus’ theory of savings in relearning, participants who were asked to memorize number–word pairs (for example, 17-snake, 23-crown) showed significant savings in the amount of time needed to relearn the number–word pairs 6 weeks later (Marmurek & Grant, 1990).

Since no one spends all day memorizing nonsense syllables, you may wonder how Ebbinghaus’ research and the “savings score” apply to real life. At some point in school, you probably had to memorize a famous speech like Dr. Martin Luther King’s “I Have a Dream.” Let’s say it took you 100 practice sessions to recite the speech flawlessly. Then, a month later, you tried memorizing it again and it only took 50 attempts. Because you cut your learning time in half (from 100 practice sessions to 50), your savings score would be 50%.

#### A FOREIGN LANGUAGE?

Learning is a lot like blazing a trail through freshly fallen snow. Your first attempt plowing through the powder is hard work and slow going, but the second time (relearning) is easier and faster because the snow is packed and the tracks already laid down. This also seems to be true for relearning a forgotten childhood language. One small study focused on native English speakers who as children had been exposed to either Hindi or Zulu to varying degrees. Although none of the adults in the study had any explicit memories of the languages, those who were under 40 were still able to distinguish sounds from their childhood languages better than members of a control group with no exposure to these languages (Bowers, Mattys, & Gage, 2009).
The implication is that people who have some knowledge of a language (even if they don’t realize it) benefit from this memory, by showing a “memory savings” if they try to learn the language again. They are a step ahead of other adults learning that language for the first time.

How Easily We Forget: Memory Slips

LO 10 Identify and explain some of the reasons why we forget.

Once the memory athletes have memorized numbers, images, and other bits of information for the World Memory Championships, how long does such data remain in their minds—an hour, a day, a week? One memory champion, Dorothea Seitz, reports that images and words can last for several days, but meaningless strings of numbers, like the hundreds of digits memorized for the “One Hour Numbers” event, tend to fade within a day (D. Seitz, personal communication, December 13, 2009).

This would probably come as no surprise to Hermann Ebbinghaus, who, in addition to demonstrating the effects of relearning, was the first to illustrate just how rapidly memories vanish. Through his experiments with nonsense syllables, Ebbinghaus (1885/1913) found that the bulk of forgetting occurs immediately after learning. If you look at his *curve of forgetting* (FIGURE 6.11), you will see his memory of word lists plunging downward the hour following learning, then leveling off thereafter. Think about how the curve of forgetting applies to you. Some of what you hear in a psychology lecture may disappear from memory as soon as you walk out the door, but what you remember a week later will probably not differ much from what you recall in a month.

![Ebbinghaus' Curve of Forgetting](FIGURE 6.11)

Ebbinghaus discovered that most forgetting occurs within 1 hour of learning and then levels off.

**ENCODING FAILURE** What exactly causes us to forget? That may depend on the stage of memory processing—encoding, storage, or retrieval—at which a given instance of memory failure occurs. Sometimes details and events we think we have forgotten were actually never encoded in the first place. Take this example: After a long and stressful day, you stop at the supermarket to pick up some blackberries and dark chocolate. While fumbling through your bag in search of your wallet, you take out your gloves and place them on the cashier’s counter, but because your attention is focused on finding your wallet, you don't even notice where you’ve placed the gloves. Then you pay and walk out the door, only to wake up the next morning wondering where you left your gloves! This is an example of *encoding failure* because the data never entered your memory system. You never registered putting your gloves on the counter in the first place, so how can you expect to remember where you left them? For a demonstration of encoding failure, take a look at the four images appearing in the *Try This*. You’ve looked at the Apple logo countless times, so it should be easy to tell if you’re looking at one that’s phony, right?

![Try This](Are any of these the correct Apple logo?)

Research from Adam B. Blake and Alan D. Castel, 2015.
If you’re like most people, you identified one of the wrong logos as correct (real Apple logo not shown), perhaps because there is no “functional reason” for you to encode the logo’s visual elements. Or maybe you have been exposed to the logo so many times that you no longer attend to its details (Blake, Nazarian, & Castel, 2015).

**Storage Failure and Memory Decay** Memory lapses can also result from storage failure. Take a moment and try to remember your high school locker combination. At one point, you knew these numbers by heart, but they have slipped your mind because you no longer use them. Many memories decay over time, but there is plenty of evidence that we can store a vast fund of information, sometimes for very long periods. Such memories might include the name of the street where you grew up (Schmidt et al., 2000), grades in college (Bahrick, Hall, & Da Costa, 2008), and factual knowledge from college courses (Conway, Cohen, & Stanhope, 1991). However, these types of memories are subject to a variety of inaccuracies and distortions, and tapping into them is not always easy.

**Tip-of-the-Tongue Phenomenon** Sometimes we know that we have knowledge of something but just can’t pull it out of storage, or retrieve it. The name of that college classmate or that new blockbuster movie, it’s just sitting on the tip of your tongue but it won’t slide off! This simple retrieval failure is called the tip-of-the-tongue phenomenon. Most of us have this feeling about once a week, but luckily we are able to retrieve the elusive phrase approximately 50% of the time (James & Burke, 2000; Schwartz, 2012). Often, we can correctly guess the first letter of the word or how many syllables it has (Hanley & Chapman, 2008). Studies suggest that the tip-of-the-tongue phenomenon becomes more common with age (Brown & Nix, 1996).

**Highly Superior Autobiographical Memory** What would happen if you had the opposite problem—that is, instead of forgetting all the time, you remembered everything? Imagine how overwhelming it would be to remember all the experiences you have had, all the people you have met, all the meals that you have eaten over the years, and so on. The ability to forget seems to have great adaptive value, because forgetting allows you to attend to what’s going on in the here and now. In simple terms, forgetting is adaptive because it clears the way for new memories (Wimber, Alink, Charest, Kriegeskorte, & Anderson, 2015). Some people, however, have an inherent ability to “retain and retrieve vast amounts of public and autobiographical events,” without trying (LePort et al., 2012, p. 13). This type of memory ability is very rare, and is known as highly superior autobiographical memory (HSAM; LePort et al., 2012; McGaugh & LePort, 2014). People with HSAM can easily recall details about personal and news events from almost every day starting in middle childhood (Pathis, 2016). In contrast, memory champions generally use mnemonics to improve their memory, and children with eidetic imagery mostly are remembering images or objects. Interestingly, individuals with this type of superior memory can remember what they had for lunch a decade ago, but when asked to remember a word list, they make a similar amount of errors as members of a control group (Pathis et al., 2013). Like the rest of us, people with HSAM can suffer from “memory distortions.”

**Proactive Interference** You now know that forgetting can stem from problems in encoding and storage. And the tip-of-the-tongue phenomenon tells us that it can also result from glitches in retrieval. Studies also show that retrieval is influenced, or in some cases blocked, by information we learn before and after a memory is made, which we refer to as interference (Waugh & Norman, 1965). If you have studied more than one foreign language, you have probably experienced interference. Suppose you take Spanish in middle school, and then begin studying Italian in college. As you try to learn Italian, you may find Spanish words creeping into your mind and confusing you;
this is an example of proactive interference, the tendency for information learned in the past to interfere with the retrieval of new material. People who learn to play a second musical instrument experience the same problem; the fingering of the old instrument interferes with the retrieval of new fingering.

**RETROACTIVE INTERFERENCE** Now let’s say you are going on a trip to Mexico and need to use the Spanish you learned back in middle school. As you approach a vendor in an outdoor market in Costa Maya, you may become frustrated when the only words that come to mind are ciao bello and buongiorno (Italian for “hello handsome” and “good day”), when you really are searching for phrases with the same meaning in Español. Here, recently learned information interferes with the retrieval of things learned in the past. We call this retroactive interference. This type of interference can also impact the musician; when she switches back to her original instrument, the fingering techniques she uses to play the new instrument interfere with her old techniques. Thus, proactive interference results from knowledge acquired in the past and retroactive interference is caused by information learned recently (FIGURE 6.12).

Although our memories fail us all the time, we manage to get by with a little help from our friends, who remind us to set our alarm clocks, study for tests, and say “happy birthday” to so and so. We have cell phones to store phone numbers and e-mail accounts to maintain addresses. The news media remind us what day it is. And then of course, there is Google.

**DIDN’T SEE THAT COMING**

Google Brain

Google. What would life be like without it? Every day, we use Google to find the answers to questions we are too embarrassed to ask out loud. It enables us to stay abreast of the latest news, provides us with immediate access to the voices and faces of friends, and helps us schedule our lives. Google is, without doubt, one of the modern brain’s greatest helpers. But here’s the question: Is all of Google’s hard work making us lazy?

Maybe “resourceful” is a better word. People essentially use computers as storage places for information they would otherwise have to remember (Sparrow & Chatman, 2013b; Sparrow, Liu, & Wegner, 2011). When researchers asked participants to read and type 40 statements referring to trivia-like information (for example, “An ostrich’s eye is bigger than its brain”), those who were told they would need the information later and that it would be available on the computer were less likely to try memorizing it than
those denied computer access. Even those who were not asked to remember the information showed better recall if they had no expectations of searching for it on the computer (Sparrow et al., 2011). We have exceptional memory systems. But if information is not applicable to us, there is no need to remember it, especially when we can search for it online (Sparrow & Chatman, 2013b). Being able to continually access information may allow us to retrieve more of it over time, perhaps overestimating how much we remember, and thus influencing how much we actually study (Sparrow & Chatman, 2013a).

Thanks to Siri, Echo, and smartphones, it seems our culture has adapted to being constantly “plugged in” and having information at our fingertips. Remember the last time you lost Internet or cell phone service? “The experience of losing our Internet connection becomes more and more like losing a friend” (Sparrow et al., 2011, p. 4).

CONNECTIONS

In Chapter 1, we introduced the concepts of expectations and bias, noting that these can produce inaccuracies in thinking and research. Here, we describe the ways in which our memories can fail. As accurate as our thoughts and memories may seem, we must be aware that they are vulnerable to error.

The Reliability of Memory

Why do we need computers to help us keep track of the loads of information flooding our brains throughout the day? The answer is simple. We can’t remember everything. We forget, and we forget often. Sometimes it’s obvious an error has occurred (I can’t remember where I left my cell phone), but other times it’s less apparent. Have you noticed that when you recall a shared event, your version is not always consistent with those of other people? As you will soon discover, memories are not reliable records of reality. They are malleable (that is, capable of being changed or reshaped by various influences) and constantly updated and revised, like a wiki. Let’s see how this occurs.

Misinformation: Can Memories Be Trusted?

Elizabeth Loftus, a renowned psychologist and law professor, has been studying memory and its reliability for the last four decades. During the course of her career, she has been an expert witness in over 200 trials. The main focus of her work is the very problem we just touched upon: If two people have different memories of an event, whom do we believe?

MEMORY RECONSTRUCTED Loftus suggests that we should not expect our accounts of the past to be identical to those of other people or to even match our own previous renditions of events. According to Loftus, episodic memories are not exact duplicates of past events (recent or distant). Instead, she and others propose a reconstructionist model of memory “in which memories are understood as creative blendings of fact and fiction” (Loftus & Ketcham, 1994, p. 5). Over the course of time, memories can fade, and

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**show what you know**

1. The ________ suggests that retrieving memories is easier in the context in which they were made.
   a. encoding specificity principle
   b. retroactive interference

2. Your friend remarks that her scores are better when she studies and takes the quiz in Starbucks than if she studies in Starbucks but takes the quiz at home. Lauren is exhibiting:
   a. context-dependent memory
   b. proactive interference.

3. Ebbinghaus reported that his memory of word lists plunged the first hour after he learned them; he displayed this in his:
   a. encoding-specificity principle.
   b. curve of forgetting.
   c. recency effect.
   d. serial position effect.

4. What are some approaches you can use to make retrieving memories easier?

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**Connections**

The tendency for new and misleading information obtained after an incident to distort one’s memory of it.
because they are permeable, they become more vulnerable to the invasion of new information. In other words, your memory of some event might include revisions to what really happened, based on knowledge, opinions, and information you have acquired since the event occurred.

Suppose you watch a debate between two presidential candidates on live television. A few days later, you see that same debate parodied on Saturday Night Live. Then a few weeks later, you try to remember the details of the actual debate—the topics discussed, the phrases used by the candidates, the clothes they wore. In your effort to recall the real event, you may very well incorporate some elements of the Saturday Night Live skit (for example, words or expressions used by the candidates). The memories we make are not precise depictions of reality, but representations of the world as we perceive it. With the passage of time, we lose bits and pieces of a memory, and unknowingly we replace them with new information. So if you need an accurate account of an event, you better get it right way. Eyewitnesses to crimes are often asked to rate their confidence in identifying a suspect. Researchers have found that “eyewitness confidence” is linked to the accuracy of the eyewitness account, but only when the confidence level is assessed at the time of the event. Simply stated, if the eyewitness has a high level of confidence in identifying a suspect at the time of the crime, her identification is more accurate (Wixted, Mickes, Clark, Gronlund, & Roediger, 2015).

**THE MISINFORMATION EFFECT** If you witnessed a car accident, how accurately would you remember it? Elizabeth Loftus and John Palmer (1974) tested the reliability of people’s memories for such an event in a classic experiment. After showing participants a short film clip of a multiple-car accident, Loftus and Palmer quizzed them about what they had seen. They asked some participants, “About how fast were the cars going when they smashed into each other?” Replacing the word “smashed” with “hit,” they asked others, “About how fast were the cars going when they hit each other?” Can you guess which version resulted in the highest estimates of speed? If you guessed “smashed,” you are correct.

One week later, the researchers asked the participants to recall the details of the accident, including whether they had seen any broken glass in the film. Although no broken glass appears in the film, the researchers nevertheless predicted there would be some “yes” answers from participants who had initially been asked about the speed of the cars that “smashed” into each other. Their predictions were correct. Participants who had heard the word “smashed” apparently incorporated a faster speed in their memories, and were more likely to report having seen broken glass. Participants who had not heard the word “smashed” seemed to have a more accurate memory of the filmed car collision. The researchers concluded that memories can change in response to new information, and specifically that the participants’ recollections were altered by the wording of a questionnaire (Loftus & Palmer, 1974). This research suggests that eyewitness accounts of accidents, crimes, and other important events might be altered by factors that come into play after the event occurs. Because memories are malleable, the wording of questions can change the way events are recalled, and care must be taken when questioning people about the past, whether it’s in a therapist’s office, a social service agency, or a police station.

Researchers have since conducted numerous studies on the misinformation effect, or the tendency for new and misleading information to distort one’s memory of an incident. Studies with a variety of participants have resulted in their “remembering” a stop sign that was really a yield sign, a screwdriver that was really a hammer, and a barn that did not actually exist (Loftus, 2005).

Prosecutors often tell people who have witnessed crimes not to speak to each other, and with good reason. Suppose two people witnessed an elderly woman being robbed.
One eyewitness remembers seeing a bearded man wearing a blue jacket swiping the woman’s purse. The other noticed the blue jacket but not the beard. If, however, the two eyewitnesses exchange stories of what they saw, the second eyewitness may unknowingly incorporate the beard into his “memory.” Information learned after the event (that is, the “fact” that the thief had a beard) can get mixed up with memories of that event (Loftus, 2005; Loftus, Miller, & Burns, 1978). If we can instill this type of “false” information into a “true” memory, do you suppose it is possible to give people memories for events that never happened? Indeed, it is.

False Memories

**LO 12** Define and explain the significance of rich false memory.

Elizabeth Loftus knows firsthand what it is like to have a memory implanted. Tragically, her mother drowned when she was 14 years old. For 30 years, she believed that someone else had found her mother’s body in a swimming pool. But then her uncle, in the middle of his 90th birthday party, told her that she, Elizabeth, had found her mother’s body. Loftus initially denied any memory of this horrifying experience, but as the days passed, she began to “recall” the event, including images of the pool, her mother’s body, and numerous police cars arriving at the scene. These images continued to build for several days, until she received a phone call from her brother informing her that her uncle had been wrong, and that all her other relatives agreed Elizabeth was not the one who found her mother. According to Loftus, “All it took was a suggestion, casually planted” (Loftus & Ketcham, 1994, p. 40), and she was able to create a memory of an event she never witnessed. Following this experience, Loftus began to study rich false memories, that is, “wholly false memories” characterized by “the subjective feeling that one is experiencing a genuine recollection, replete with sensory details, and even expressed with confidence and emotion, even though the event never happened” (Loftus & Bernstein, 2005, p. 101).

Would you believe that about 25% of participants in rich false memory studies are able to ‘remember’ an event that never happened? Using the “lost in the mall” technique, Loftus and Pickrell (1995) showed just how these imaginary memories take form. The researchers recruited a pair of family members (for example, parent–child or sibling–sibling) and then told them they would be participating in a study on memory. With the help of one of the members of the pair (the “relative”), the researchers recorded three true events from the pair’s shared past and created a plausible story of a trip to a shopping mall that never happened. Then they asked the true “participant” to recall as many details as possible about each of the four events (remember, only three of the events were real), which were presented in a book provided by the researchers. If the participant could not remember any details from an event, he was instructed to write, “I do not remember this.” In the “lost in the mall” story, the participant was told that he had been separated from the family in a shopping mall around the age of 5. According to the story, the participant began to cry, but was eventually helped by an elderly woman and was reunited with his family. Mind you, the “lost in the mall” episode was pure fiction, but it was made to seem real through the help of the participant’s relative (who was working with the researchers). Following a series of interviews, the researchers concluded that 29% of the participants were able to “recall” either part or all of the fabricated “lost in the mall” experience (Loftus & Pickrell, 1995). These findings may seem shocking (they certainly caused a great uproar in the field), but keep in mind that a large majority of the participants did not “remember” the fabricated event (Hyman, Husband, & Billings, 1995; Loftus & Pickrell, 1995).
CONTROVERSIES

The Debate over Repressed Childhood Memories

Given what you learned from the “lost in the mall” study, do you think it’s possible that false memories can be planted by psychotherapy? Imagine a clinical psychologist or psychiatrist who firmly believes that her client was sexually abused as a child. The client has no memory of abuse, but the therapist is convinced that the abuse occurred and that the traumatic memory for it has been repressed, or unconsciously pushed below the threshold of awareness (see Chapter 11). Using methods such as hypnosis and dream analysis, the therapist helps the client resurrect a “memory” of the abuse (that presumably never occurred). Angry and hurt, the client then confronts the “abuser,” who happens to be a close relative, and forever damages the relationship. Believe it or not, this scenario is very plausible. Consider these true stories picked from a long list:

• With the help of a psychiatrist, Nadean Cool came to believe that she was a victim of sexual abuse, a former member of a satanic cult, and a baby killer. She later claimed these to be false memories brought about in therapy (Loftus, 1997).

• Under the influence of prescription drugs and persuasive therapists, Lynn Price Gondolf became convinced that her parents molested her during childhood. Three years after accusing her parents of such abuse, she concluded the accusation was a mistake (Loftus & Ketcham, 1994).

• Laura Pasley “walked into her Texas therapist’s office with one problem, bulimia, and walked out with another, incest” (Loftus, 1994, p. 44).

In the history of psychology, few topics have stirred up as much controversy as repressed memories, and the debate is still ongoing today (Brewin & Andrews, 2014; Patihis, Ho, Tingen, Lilienfeld, & Loftus, 2014; Patihis, Lilienfeld, Ho, & Loftus, 2014). Some psychologists believe that painful memories can indeed be repressed and recovered years or decades later, with a distinct gap between scientists who are skeptical of this and practitioners who are less so (Knapp & VandeCreek, 2000; Patihis, Ho, et al., 2014). The majority, however, would agree that the studies supporting the existence of repressed memories have many shortcomings (Piper, Lillevik, & Kritzer, 2008). Although childhood sexual abuse is shockingly common, with approximately 18% of girls and 8% of boys being affected worldwide (Stoltenborgh, Bakermans-Kranenburg, Alink, & IJzendoorn, 2015), there is not good evidence that these traumas are repressed. Even if they were, many believe retrieved memories of them would likely be inaccurate (Patihis, Ho, et al., 2014; Roediger & Bergman, 1998). Many trauma survivors face quite a different challenge—letting go of painful memories that continue to haunt them. (See the discussion of posttraumatic stress disorder in Chapter 12.)

The American Psychological Association (APA) and other authoritative mental health organizations have investigated the repressed memory issue at length. In 1998 the APA issued a statement offering its main conclusions, summarized below:

• Sexual abuse of children is very common and often unrecognized, and the repressed memory debate should not detract attention from this important issue.

• Most victims of sexual abuse have at least some memory of the abuse.

• Memories of past abuses can be forgotten and remembered at a later time.
• People sometimes do create false memories of experiences they never had.
• We still do not completely understand how accurate and flawed memories of childhood abuse are formed (APA, 1998a).

Keep these points in mind next time you hear the term “repressed memory” tossed around in television talk shows, Internet posts, or casual conversations. You are now prepared with scientific knowledge to evaluate claims about repressed memories, so ask critical questions and maintain a healthy degree of skepticism. If you or someone you know is dealing with issues related to abuse, seek help from a licensed psychotherapist (APA, n.d.-c).

The main message of this section is that memory is malleable, or changeable. What are the implications for eyewitness accounts, especially those provided by children? If we are aware of how questions are structured and understand rewards and punishments from the perspective of a child, then the interview will produce fewer inaccuracies (Sparling, Wilder, Kondash, Boyle, & Compton, 2011). Researchers have found that having children close their eyes increases the accuracy of the testimony (Vredeveldt, Baddeley, & Hitch, 2014), but relying solely on their accounts has contributed to many cases of mistaken identity. In addition, the presence of someone in a uniform appears to put added pressure on child eyewitnesses, resulting in more guessing and inaccurate recall (Lowenstein, Blank, & Sauer, 2010).

The interrogation of people at any age can lead to serious, lifelong consequences. Following a series of interviews using suggestive memory-retrieval methods, 70% of the young adults participating in one study generated rich false memories of criminal behavior they had not committed during adolescence. They recalled incidents involving theft and assault, including interactions with the police that never happened! The implication is that some false confessions might be influenced by interrogation techniques that result in the false recall of crimes that were not committed. A person can believe he committed a crime that never happened, falsely confess to it, and then be wrongly convicted (Porter & Baker, 2015; Shaw & Porter, 2015).

Before you read on, take a minute and allow the words of Elizabeth Loftus to sink in: “Think of your mind as a bowl filled with clear water. Now imagine each memory as a teaspoon of milk stirred into the water. Every adult mind holds thousands of these murky memories. . . . Who among us would dare to disentangle the water from the milk?” (Loftus & Ketcham, 1994, pp. 3–4). What is the basis for all this murkiness? Time to explore the biological roots of memory.
The Biology of Memory

What did you do today? Did you have breakfast, brush your teeth, put your clothes on, drive your car, read an assignment, text a friend? Whatever you did, we are sure of one thing: It required a whole lot of memory. You could not send a text message without knowing how to spell, read, and use a cell phone—all things you had to learn and remember. Likewise, you could not drive without remembering how to unlock your car, start the engine, use the pedals. Memory is involved in virtually everything you do.

If memory is behind all your daily activities, important processes must be occurring in the brain to make this happen: both on the macro (large) and micro (small) scale. But as we learned from Clive's example, these processes are fragile and can be profoundly disrupted. Exploring the causes of memory failure can help us understand the biological basis of memory.

Amnesia

THE AFTERMATH  In the months and years following Clive's illness, researchers administered many tests to assess his cognitive functioning. They found his IQ to be within an average range but his ability to remember past events deeply impaired. When prompted to name as many musical composers as possible in 1 minute, Clive—a man who had devoted his career to the study of music—could only produce four: Mozart, Beethoven, Bach, and Haydn. He denied that dragonflies have wings and claimed he had never heard of John F. Kennedy (Wilson et al., 1995).

Clive was even more disabled when it came to developing new memories. Initially, he could not hold onto incoming information for more than a blink of an eye. If his wife Deborah left the room, even for a short trip to the restroom, he would welcome her back as if she had been away for years—embracing, celebrating, sometimes weeping. “How long have I been ill?” he would ask, forgetting the answer and repeating himself within seconds (Wearing, 2005, p. 181).

Amnesia, or memory loss, can result from either a physical or psychological condition. There are different types and degrees of amnesia, ranging from extreme (losing decades of autobiographical memories) to mild (temporarily forgetting people's names after a concussion).

ANTEROGRADE AMNESIA According to researchers, Clive suffers from “a more severe anterograde amnesia than any other patient previously reported” (Wilson et al., 1995, p. 680). Anterograde amnesia (ANT-er-oh-grade) is the inability to “lay down” or create new long-term memories (figure 6.13 on page 266), and it is generally caused by damage or injury to the brain, resulting from surgery, alcohol, head trauma, or illness. Someone with anterograde amnesia cannot form memories of events and experiences that occur following the brain damage, regardless of its cause. People affected by anterograde amnesia may be incapable of holding down a job, as their inability to lay down new memories affects their capacity to remember daily tasks. For Clive, his short-term memory still functioned to a certain extent, but he could only absorb and process information for several seconds before it was lost. From his perspective, every experience was fresh, and every person (with the exception of some he knew well from the past) a total stranger.
A second type of memory loss is retrograde amnesia, an inability to access memories created before a brain injury or surgery (Brandt & Benedict, 1993; Figure 6.13). With retrograde amnesia, a person has difficulty retrieving old memories, though how “old” depends on the extent of trauma to the brain. People with retrograde amnesia generally remember who they are and the most important events of their earlier lives (Manns, Hopkins, & Squire, 2003; Squire & Wixted, 2011). Remember that retrograde refers to the inability to access old memories (think of “retro,” meaning in the past, to help you distinguish between the terms), and anterograde refers to the inability to create new memories.

Clive suffered from retrograde amnesia in addition to his anterograde amnesia. While he appeared to retain a vague outline of his past (hazy information about his childhood, the fact that he had been a choral scholar at Clare College, Cambridge, and so on), he could not retrieve the names of his children unless prompted. And although Clive’s children were all adults when he developed encephalitis, he came out of the illness thinking they were young children. The retrograde amnesia has improved, but only minimally. In 2005, for example, Clive asked his 40-something son what subjects he was studying in grammar school (equivalent to American high school). Nowadays when inquiring about his children, Clive simply asks, “What are they doing?” (D. Wearing, personal communication, June 18 and 25, July 11, 2013).

In spite of the severe retrograde and anterograde amnesia, some of Clive’s memory functions continued to operate quite well. At one point, Deborah arranged for Clive to be reunited with the singers from the London Lassus Ensemble, a group he had conducted for more than a decade before his illness. While he appeared to retain a vague outline of his past (hazy information about his childhood, the fact that he had been a choral scholar at Clare College, Cambridge, and so on), he could not retrieve the names of his children unless prompted. And although Clive’s children were all adults when he developed encephalitis, he came out of the illness thinking they were young children. The retrograde amnesia has improved, but only minimally. In 2005, for example, Clive asked his 40-something son what subjects he was studying in grammar school (equivalent to American high school). Nowadays when inquiring about his children, Clive simply asks, “What are they doing?” (D. Wearing, personal communication, June 18 and 25, July 11, 2013).

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How is it possible that some of Clive’s long-term memories were blotted out, while others, such as how to conduct music, remained fairly clear? The evidence...
suggests that different types of long-term memories have distinct processing routes in the brain. Thus, damage to one area of the brain may impair some types of memory but not others. Let’s take a closer look at where memories seem to be stored in the brain.

**Where Memories Live in the Brain: A Macro Perspective**

**LO 14** Identify the brain structures involved in memory.

A few years after the onset of Clive’s illness, doctors evaluated his brain using an MRI scan. A troubling picture emerged; the virus had destroyed many parts of his brain, notably the **hippocampus**, which plays a vital role in the creation of new memories (Wilson et al., 2008).

Only in the last 50 years have scientists come to appreciate the role of the hippocampus in memory (INFOTRACE 6.2 on page 268). Back in the 1920s, psychologist Karl Lashley set out to find a **memory trace**: the physical spot where memories are etched in the brain, also called an *engram*. Lashley selected a group of rats that had learned the layout of specific mazes, and then made large cuts at different places in their cortices to see how this affected their memory of the mazes. No matter where Lashley sliced, the rats still managed to maneuver their way through the mazes (Costandi, 2009, February 10; Lashley, 1950). These findings led Lashley and other scientists to believe that memory is spread throughout the brain rather than localized in a particular region (Costandi, 2009, February 10; Kandel & Pittenger, 1999). **Connectionism** is a model that suggests our memories are distributed throughout the brain in a network of interlinked neurons.

**THE CASE OF H.M.** Henry Molaison (better known as “H.M.”) forced scientists to completely reevaluate their understanding of the brain’s memory system. From the onset of his amnesia in 1953 until his death in 2008, H.M. served as a research participant for some 100 scientists (Corkin, 2002), making him the most extensively studied amnesic patient.

H.M.’s brain troubles began at the age of 10, a year or so after being knocked unconscious in a bicycle accident. He began to experience seizures, which worsened with age and eventually became so debilitating that he could no longer hold a steady job. Antiseizure medications were unsuccessful in controlling his seizures, so at the age of 27, H.M. opted for an experimental surgery to remove parts of his brain: the temporal lobes (just beneath the temples), including the hippocampus (Scoville & Milner, 1957).

H.M.’s surgery succeeded in reining in his epilepsy but left his memory in shambles. Upon waking from the operation, he could no longer find his way to the bathroom or recognize the hospital workers caring for him. He played with the same jigsaw puzzles and read the same magazines day after day as if he were seeing them for the first time (Scoville & Milner, 1957).

Like Clive, H.M. suffered from profound **anterograde amnesia**, the inability to encode new long-term memories, and a milder form of **retrograde amnesia**, trouble retrieving existing memories from storage. Although H.M. had difficulty recalling what occurred during the few years leading up to his surgery (Scoville & Milner, 1957), he did remember events from the more distant past, for example, the 1929 stock market crash and the events of World War II (Carey, 2008, December 4).

**Project H.M.** Dr. Jacopo Annese, director of the Brain Observatory at the University of San Diego, stands in front of a massive digital image rendered from a slice of brain tissue preserved on a slide. Dr. Annese and his team carved the brain of amnesic Henry Molaison, or “H.M.,” into 2,401 slices to create a digital model (Annese et al., 2014). John Gibbins/ZUMApress/Newscom.
INFOGRAPHIC 6.2

Tracking Memory in the Brain

Whether with lab rats or case studies, psychologists have spent decades tracking the location of memory in the brain. What they’ve found so far should be no surprise: Memory is a complex system involving multiple structures and regions of the brain. Memory is formed, processed, and stored throughout the brain, and different types of memory have different paths. So to find memory in the brain, it helps to know your way around the brain’s structures. Remembering the amygdala’s role in processing basic emotion, for instance, can help you understand its role in processing the emotional content of memories.

In an attempt to control the disabling seizures of a man named Henry Molaison (H.M.), doctors surgically removed portions of his brain, including the hippocampus. The surgery affected H.M.’s memory. He had profound anterograde amnesia: He could tap into old memories, but he could no longer make new explicit memories. However, he could still create implicit memories. Using information gathered about H.M.’s brain, scientists have been able to directly connect the hippocampus to the creation of new explicit memories.

Through his experiments slicing the cortices of rats that had learned to navigate mazes, Karl Lashley concluded that complex memories are not localized to a particular region in the cortex, but are instead widely distributed. Later research has established the interrelated roles of specific structures in the process of encoding, storing and retrieving memories.

In a process called memory consolidation, which occurs in the hippocampus, memories are moved to other parts of the cerebral cortex for long-term storage. Research on this topic is ongoing. For instance, scientists have been able to link explicit memory storage to areas of the brain where the original sensation was processed (see Harris, Petersen, & Diamond, 2001).

Forming New Memories

In an attempt to control the disabling seizures of a man named Henry Molaison (H.M.), doctors surgically removed portions of his brain, including the hippocampus. The surgery affected H.M.’s memory. He had profound anterograde amnesia: He could tap into old memories, but he could no longer make new explicit memories. However, he could still create implicit memories. Using information gathered about H.M.’s brain, scientists have been able to directly connect the hippocampus to the creation of new explicit memories.

After his death, H.M.’s brain was cut into over 2,000 slices that were preserved and digitized for research.

Lashley kept a careful record of the sizes and locations of lesions made in each rat as part of his experiments.

Storing Memories

Through his experiments slicing the cortices of rats that had learned to navigate mazes, Karl Lashley concluded that complex memories are not localized to a particular region in the cortex, but are instead widely distributed. Later research has established the interrelated roles of specific structures in the process of encoding, storing and retrieving memories.

In a process called memory consolidation, which occurs in the hippocampus, memories are moved to other parts of the cerebral cortex for long-term storage. Research on this topic is ongoing. For instance, scientists have been able to link explicit memory storage to areas of the brain where the original sensation was processed (see Harris, Petersen, & Diamond, 2001).
H.M. maintained a working implicit memory, which he demonstrated in an experiment involving the complex task of tracing a pattern reflected in a mirror. With repeated practice sessions (none of which he remembered), H.M. improved his performance on the drawing task, learning it as well as someone without amnesia (Gabrieli, Corkin, Mickel, & Growdon, 1993). Clive can also acquire new implicit memories, but his ability is very limited. According to Deborah, it took years for Clive to learn how to get to his bedroom in the small community residence where he moved after leaving the hospital (Wearing, 2005).

**THE ROLE OF THE HIPPOCAMPUS** Imagine you are a scientist trying to figure out exactly what role the hippocampus plays in memory. Consider the facts you know about H.M.: (1) He has virtually no hippocampus; (2) he has lost the ability to make new explicit memories, yet can create implicit memories; and (3) he can still tap into memories of the distant past. So what do you think the hippocampus does? Evidence suggests that the hippocampus is essential for creating new explicit memories but not implicit memories. Researchers have also shown that explicit memories are processed and stored in other parts of the brain, including the temporal lobes and areas of the frontal cortex (García-Lázaro, Ramírez-Carmona, Lara-Romero, & Roldan-Valadez, 2012).

As in H.M.’s case, Clive’s ability to form explicit memories is profoundly compromised, largely a result of the destruction of his hippocampus. Yet Clive also struggles with the creation of implicit memories—not surprising given the extensive damage to other regions of his brain, such as the amygdala and temporal lobes (Wilson et al., 2008). Studies have zeroed in on other brain areas, such as the cerebellum and amygdala, as processing hubs for implicit memory (Thompson & Kim, 1996; Thompson & Steinmetz, 2009). The amygdala plays a central role in the processing of emotional memories (García-Lázaro et al., 2012). See Infographic 6.2 for more information about memory processing in the brain.

So although the hippocampus plays a central role in laying down new memories, it does not appear to serve as their ultimate destination. This process of memory formation, which moves a memory from the hippocampus to other areas of the brain, is called memory consolidation (Squire & Bayley, 2007). The consolidation that begins in the hippocampus allows for the long-term storage of memories. According to Kandel and Pittenger (1999): “The final locus of storage of memory is widely assumed to be the cerebral cortex, though this is a difficult assertion to prove” (p. 2041). As for retrieval, the hippocampus appears to be in charge of accessing young memories, but then passes on that responsibility to other brain regions as memories grow older (Smith & Squire, 2009).

This idea that the hippocampus is essential for creating explicit memories (as opposed to implicit memories) is supported by what we know about infantile amnesia, that is, the inability to remember events from our earliest years. Most adults cannot remember events before the age of 3, though it is not clear why. Some researchers suggest that it is because the hippocampus and frontal cortex, both important for the creation of long-term explicit memories, are not fully developed in children (Bauer, 2006; Willoughby, Desrocher, Levine, & Rovet, 2012). Simply stated, young children do not construct complete episodic memories of their experiences (Bauer & Larkina, 2014). We are less likely to forget memories starting around age 7 due to the type of memories we begin generating (more elaborate and personally relevant). The efficiency of how the memories are formed (more effective neural processes) also make these memories “more impervious to the ravages of forgetting” (Bauer, 2015, p. 225).

For most people, the average age of first memory is from an event that happened around the age of 3 or 4. What’s your first memory?
The macrolevel perspective presented in this section allows us to see the “big picture” of memory, but what’s going on microscopically? Next we will focus on the important changes occurring in and between neurons.

Where Memories Live in the Brain: A Micro Perspective

LO 15 Describe long-term potentiation and its relationship to memory.

How does your brain change when you learn a new driving route to school? If we could peer into your skull, we might see a change in your hippocampus. Now imagine what might happen in the brain of a taxicab driver in London, who must memorize the 25,000 streets in the city, including their businesses and landmarks. As one study found, London taxicab drivers with greater time spent on the job had structural changes in some regions of the hippocampus, particularly to an area that processes “spatial knowledge” (Maguire, Woollett, & Spiers, 2006; Rosen, 2014, November 10). Zooming in for a closer look, we might actually see changes at the level of the neuron. If you are looking for a memory imprint, the best place to look is the synapse.

**LONG-TERM POTENTIATION** As it turns out, the more neurons communicate with each other, the better the connections between them. **Long-term potentiation** occurs when sending neurons release neurotransmitters more effectively, and receiving neurons become more sensitive, boosting synaptic strength for days or even weeks (Lynch, 2002;
Malenka & Nicoll, 1999; Whitlock, Heynen, Shuler, & Bear, 2006). In other words, long-term potentiation refers to the increased efficiency of neural communication over time, resulting in learning and the formation of memories. Researchers suggest long-term potentiation may be the biological basis for many kinds of learning. As you learn a new skill, for example, the neurons involved in performing that skill increase their communication with each other. It might start with a somewhat random firing of neurons, but eventually the neurons responsible for the new skill develop pathways through which they communicate more efficiently. Having trouble visualizing the process? Imagine this scenario: Your college has opened a new campus with an array of brand-new buildings, but it has yet to construct the sidewalks connecting them. In order to go from one class to the next, students have to wade through tall grass and weeds. All the trampling eventually gives way to a system of paths linking the buildings, including a multitude of efficient paths that develop among them. Long-term potentiation of neural connections occurs in a similar fashion: Over time, the communication among neurons improves and strengthens, allowing for the skill to develop and become more natural (Whitlock et al., 2006). These paths represent how a skill, whether tying your shoes or driving a stick shift, is learned and thus becomes a memory.

APLYSIA Amazingly, we have learned much about long-term potentiation from the sea slug Aplysia, which has only about 20,000 neurons (Kandel, 2009)—a little easier to work with than the billions of neurons in a human brain. The fact that the sea slug’s synapses are relatively easy to examine individually also allows for the intensive study of habituation and other processes involved in classical conditioning. Studies using sea slugs as their subjects indicate that long-term potentiation, or increases in synaptic “strength,” is associated with learning and memory. What can a sea slug learn? They can be classically conditioned to retract their gills in response to being squirted with water, resulting in structural changes to both presynaptic and postsynaptic cells, including changes to connections between neurons (Kandel, 2009)—evidence of long-term potentiation. So never, ever complain that you cannot learn: If a sea slug can do it, so can you!

ALZHEIMER’S DISEASE On a less positive note, disruptions in long-term potentiation appear to be at work in Alzheimer’s disease, a progressive, devastating brain illness that causes cognitive decline, including memory, language, and thinking problems. Alzheimer’s affects upwards of 5 million Americans (National Institute on Aging, n.d.). The disease was first discovered by Alois Alzheimer, a German neuropathologist, in the early 1900s. He had a patient with severe memory problems whose autopsy revealed that neurons in her brain had become tangled like the wires of your earbud headphones. These neurofibrillary tangles, as they came to be called, were eventually shown to result from twisted protein fibers accumulating inside brain cells. In addition to the tangles, the other distinctive sign of Alzheimer’s is the presence of amyloid plaques, protein clumps that build up between neurons, blocking their lines of communication (Vingtdeux, Davies, Dickson, & Marambaud, 2011).

NATURE AND NURTURE Why Alzheimer’s?

By the year 2050, Alzheimer’s disease is expected to affect approximately 106 million people in the United States, with an associated annual cost of $1.2 trillion (Alzheimer's Association, 2013b; Demartini, Schilling, da Costa, & Carlini, 2014). Clearly, it is imperative that we uncover the causes of Alzheimer’s disease and take steps to prevent it.
While we still don’t have a solid understanding of what causes Alzheimer’s, we know some forms of the disease are inherited. People who have a first-degree relative (a parent, sibling, or child) with Alzheimer’s have a higher risk for developing the disease. Researchers have zeroed in on a certain gene, APOE\(\varepsilon 4\), which seems to predispose people to Alzheimer’s (Liu, Kanekiyo, Xu, & Bu, 2013). But we also know that factors such as diet and exercise can influence the development and progression of the disease (Alzheimer’s Association, 2013b). Being obese and sedentary can heighten one’s risk; in fact, studies suggest that the standard American diet (one that is high in sugar, fats, and processed food, and low in fruits, vegetables, and whole grains) can cause “nutrient deficiency and inflammation that could impact cognition directly” (Graham et al., 2016, p. 2). Even the air we breathe may play a role, as long-term exposure to air pollution has been linked to cognitive decline in older adults (Ailshire & Clarke, 2014; Gatto et al., 2014; Weuve et al., 2012).

Alzheimer’s disease clearly results from a combination of nature and nurture. While we can’t change our genetic code, we can take preventative measures to reduce our risk of cognitive decline in general. Healthy eating; staying physically, mentally, and socially active; and doing our part to reduce pollution are good places to start.

No cure for Alzheimer’s disease exists, and current treatments focus only on reducing the severity of symptoms rather than correcting the brain damage responsible. But there is also reason to be hopeful. Promising new drugs are coming down the pipeline, and some preliminary evidence suggests that simple lifestyle changes, like becoming more physically active and pursuing intellectually and socially stimulating activities, may actually decrease the speed and severity of cognitive decline (Hertzog, Kramer, Wilson, & Lindenberger, 2009, July/August; Walsh, 2011; Wilson & Bennett, 2003). Additional good news comes from research suggesting that we should not think of cognitive decline as inevitable in aging. We have more control of aging than previously thought, especially when we focus on the lifelong possibilities of learning and independence (Hertzog et al., 2009). Furthermore, it’s not only the strengthening of synapses that makes for enduring memories, but also the activation of new ones (Yu, Ponomarev, & Davis, 2004), and this process could offset cognitive decline (Table 6.2).

### Table 6.2 Facts About Memory Loss

<table>
<thead>
<tr>
<th>Category</th>
<th>Facts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Family</td>
<td>There is no definitive way to know whether you or a family member will suffer from a neurocognitive disorder; most cases result from a complex combination of genetic, environmental, and lifestyle factors.</td>
</tr>
<tr>
<td>Exercise</td>
<td>Studies of both animals and people have linked physical exercise to a variety of positive changes in the brain, including enhanced blood flow, increased thickness of the cortex, and less age-related deterioration of the hippocampus (Polidori, Nelles, &amp; Pientka, 2010). Some research suggests that people who begin exercising in their thirties (and stick with it) experience less cognitive decline than their sedentary peers by the time they reach their forties and fifties (Hertzog, Kramer, Wilson, &amp; Lindenberger, 2009, July/August), although consistent exercise at any age has lasting cognitive benefits (Cotman &amp; Berchtold, 2002; Kramer, Erickson, &amp; Colcombe, 2006).</td>
</tr>
<tr>
<td>Intellectual</td>
<td>Intellectually engaging activities such as reading books and newspapers, writing, drawing, and solving crossword puzzles have been associated with a lower risk of memory loss (Hertzog et al., 2009, July/August; Wang, Karp, Winblad, &amp; Fratiglioni, 2002).</td>
</tr>
<tr>
<td>Social activity</td>
<td>Being socially active and hooked into social networks may reduce the risk of developing dementia (Fratiglioni, Paillard-Borg, &amp; Winblad, 2004).</td>
</tr>
</tbody>
</table>

Memory loss needn’t be an inevitable part of aging. Above are some facts you should know.
1. ________ refers to the inability to lay down new long-term memories, generally resulting from damage to the brain.
   a. Anterograde amnesia
   b. Retrograde amnesia
   c. Infantile amnesia
   d. Long-term potentiation

2. The ________ is a pair of curved structures in the brain that play a central role in memory.
   a. engram
   b. temporal lobe
   c. hippocampus
   d. aplysia

3. ________ is the process of memory formation, which moves a memory from the hippocampus to other areas of the brain.
   a. Long-term potentiation
   b. Memory consolidation
   c. Priming
   d. The memory trace

4. Infantile amnesia makes it difficult for people to remember events that occurred before the age of 3. What is your earliest memory and how old were you when that event occurred?

---

**CHRONIC TRAUMATIC ENCEPHALOPATHY** Similar in some ways to Alzheimer’s disease, chronic traumatic encephalopathy (CTE) is distinct in its progression and impact on memory (McKee et al., 2013). CTE is a neurodegenerative disease that leads to atypical deposits of the tau protein throughout various regions in the brain as a result of repeated mild traumatic brain injury. This disease affects football players, soccer players, wrestlers, rugby players, boxers, hockey players, lacrosse players, combat war veterans, and many other people who have suffered impact to the head (Maroon et al., 2015; McKee et al., 2016). Symptoms include significant memory issues, impulsivity, aggression, insomnia, and depression. CTE is progressive, and symptoms may not appear for months to years following the impact, and can only be diagnosed after death (Kirk, Gilmore, & Wiser, 2013; McKee et al., 2013). Who’s at risk and what are some of the more obvious symptoms of CTE? Discover the answers in INFOGRAPHIC 6.3 on page 274.

As we continue to learn more about CTE, parents must make difficult decisions about the type of sports they encourage their children to participate in. Approximately 4 million concussions are reported every year as a result of playing sports, but it is estimated that 50% of all concussions may not be reported (Harmon et al., 2013). Further, the subconcussive hits (those not hard enough to cause a concussion) may also put athletes at risk for the development of this disease (Harmon et al., 2013).

Like many topics psychologists study, the biological mechanisms that give rise to memory remain somewhat mysterious. We know we have memories, we know they are formed in the brain, and we know the brain is a physical entity; yet we still don’t know exactly how we go from an array of firing neurons to a vivid recollection of your 21st birthday bash, your high school prom, or the image of Bruno Mars banging on his drums at the Super Bowl halftime show. Studies attempting to test the various theories of memory formation are inconclusive, often generating more questions than answers. But one thing seems certain: Memory researchers face plenty of important work ahead.

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**FINAL THOUGHTS** At this point, you may be wondering what became of Clive Wearing. After living in the hospital for 7 years, Clive moved to a country residence specially designed for people suffering from brain injuries. As he left the hospital, some of the staff members offered him a farewell and said they would miss him. Addressing them with a polite bow, Clive exclaimed, “You’re the first people I’ve seen!” When Deborah would visit Clive in his new home, she found him happy and relaxed, spending much of his time on walks through gardens and the local village (Wearing, 2005, p. 293). In 2002 Clive and Deborah renewed their marriage vows. Clive participated fully in the service, reciting scripture he had memorized during his career as a professional singer decades before (D. Wearing, personal communication, June 10, 2013). After the ceremony, he had no recollection of what had taken place but nevertheless was very happy, laughing and devouring sponge cake (Wearing, 2005).
Chronic Traumatic Encephalopathy (CTE) is a progressive neurodegenerative disease caused by a single or repeated blow to the head. CTE affects athletes of many types, combat war veterans, and many others who experience head trauma (Maroon et al., 2015; McKee et al., 2016). The symptoms, which may not appear for months or years after the injury, include changes to memory, emotions, thinking, and personality. CTE is somewhat similar to other neurodegenerative diseases like Alzheimer’s and Parkinson’s in that it can impair memory, movement, and the ability to plan and carry out everyday tasks (McKee et al., 2013).

In 2012, after 20 seasons as an NFL player, Junior Seau committed suicide at age 43. In the years leading to his death, Seau’s family noticed a change in his thinking, personality, and enthusiasm for the game. Impulsive gambling, alcoholism and violence became the new conversation around the man once known as a beloved philanthropist (FAINARU-WADA, 2013 FEBRUARY 15). Upon his death, his brain showed the hallmarks of CTE (NINDS, 2013 JANUARY 10).

Retired soccer star Brandi Chastain has announced she will donate her brain to research. Chastain believes this will be a bigger legacy than her goal-winning shot in the 1999 World Cup. Like many soccer players, Chastain advocates the banning of headers in youth soccer. (BRANCH, 2016 MARCH).

The Progression of CTE

Stage 1
Tau protein accumulates locally in the cortex.
**Symptoms:** headaches, and difficulty maintaining focus.

Stage 2
The damage spreads to surrounding areas.
**Symptoms:** short-term memory impairment, mood swings, depression, explosive temper, and continued headaches and trouble focusing.

Stage 3
Damage continues to spread, reaching areas such as the hippocampus, amygdala, and brainstem.
**Symptoms:** memory loss, difficulty planning and carrying out tasks, “visuospatial abnormalities,” and ongoing difficulties with mood and attention.

Stage 4
Widespread damage across many regions of the brain, including the medial temporal lobe, hypothalamus, and thalamus.
**Symptoms:** worsening of existing symptoms, along with language difficulties and paranoia. Severe memory loss.

How does CTE differ from other neurodegenerative diseases such as Alzheimer’s? Symptoms associated with CTE typically present around age 40, while those of Alzheimer’s generally appear around 60. Changes in thinking, cognition, and personality are common symptoms of CTE, while Alzheimer’s is typically associated with memory problems (FREQUENTLY ASKED QUESTIONS, n.d.). However, emerging research suggests that behavioral changes and “neuropsychiatric symptoms” (depression or anxiety, for example) may signal the beginning of the disease process in Alzheimer’s patients (DONOVAN et al., 2014; ISMAIL, 2016).
 summary of concepts

LO 1 Define memory. (p. 235)
Memory refers to the information collected and stored in the brain that is generally available for later use. Exactly how the brain absorbs information from the outside world and files it for later use is still not completely understood. However, scientists have proposed many theories and constructed various models to help explain how the brain processes, or works on, data on their way to becoming memories.

LO 2 Describe the processes of encoding, storage, and retrieval. (p. 236)
Encoding is the process through which new information enters our memory system. Information is taken in by our senses and converted into neural activity that travels to the brain, and if successfully encoded, it is stored. Storage preserves the information for possible recollection in the future. Retrieval is the process of accessing information stored in memory.

LO 3 Explain the stages of memory described by the information-processing model. (p. 239)
According to the information-processing model, the brain has three types of memory storage associated with the stages of memory: sensory memory, short-term memory, and long-term memory.

LO 4 Describe sensory memory. (p. 240)
Data picked up by the senses enter sensory memory, where sensations are registered. Here, almost exact copies of our sensations are processed for a very brief moment. Information from the outside world floods our sensory memory through multiple channels. Although this stage of memory is fleeting, it is critical to the creation of memories.

LO 5 Summarize short-term memory. (p. 242)
Short-term memory is the second stage of the original information-processing model. This is where information is temporarily maintained and processed before moving on to long-term memory or leaving the memory system. Short-term memory has a limited capacity; how long and how much it can hold depends on how much you are distracted by other cognitive activities. Through maintenance rehearsal, we can prolong short-term memory.

LO 6 Give examples of how we can use chunking to improve our memory span. (p. 242)
Grouping numbers, letters, or other items into meaningful subsets, or “chunks,” is an effective strategy for juggling and increasing the amount of information in short-term memory. In addition, chunking can help nudge the same information into long-term memory.

LO 7 Describe working memory and its relationship to short-term memory. (p. 243).
The active processing component of short-term memory, working memory, has four important parts. The phonological loop is responsible for working with verbal information for brief periods of time. The visuospatial sketchpad is where visual and spatial data are briefly stored and manipulated. The central executive directs attention, makes plans, coordinates activities, and determines what information should be ignored. The episodic buffer is where information from the phonological loop, visuospatial sketchpad, and long-term memory can all be brought together temporarily, as directed by the central executive.

LO 8 Describe long-term memory. (p. 245)
Long-term memory is a stage of memory with essentially unlimited capacity. Long-term memories may be explicit or implicit. Explicit memory is the type of memory you are aware of having and can consciously express, and can be further divided into semantic and episodic memory. Semantic memory pertains to general facts about the world, while episodic memory is your record of the memorable experiences in your life. Implicit memory is for something you know or you know how to do, but that might be automatic or unconscious, and therefore difficult to articulate.

LO 9 Illustrate how encoding specificity relates to retrieval cues. (p. 254)
Retrieval cues are stimuli that help you retrieve stored information that is difficult to access. The encoding specificity principle states that memories are more easily recalled when the context and cues at the time of encoding are similar to those at the time of retrieval. Thus, the context (external or internal) at the time of encoding and retrieval...
provides retrieval cues. Priming, recall, and recognition also play a role in the retrieval of stored information.

**LO 10** Identify and explain some of the reasons why we forget. (p. 257)

Memory failure may occur during any of the three stages of memory processing: encoding, storage, and retrieval. One example of memory failure is the tip-of-the-tongue phenomenon, which occurs when we cannot retrieve a stored memory.

**LO 11** Explain how the malleability of memory influences the recall of events. (p. 260)

Eyewitness accounts are not always reliable because people’s memories are far from perfect. Memories can change over time, which means we lose bits and pieces of a memory, and unknowingly replace them with new information; this can influence the recall of the event.

**LO 12** Define and explain the significance of rich false memory. (p. 262)

Rich false memories are experienced as true recollections of an event, including details, emotions, and confidence that the event occurred, although it never did. Some researchers have managed to implant false memories in the minds of participants.

**LO 13** Compare and contrast anterograde and retrograde amnesia. (p. 265)

There are varying degrees of amnesia, or memory loss, due to medical or psychological conditions. Anterograde amnesia is the inability to “lay down” or create new long-term memories, and is generally caused by damage to the brain resulting from surgery, alcohol, head trauma, or illness. Retrograde amnesia is an inability to access memories created before a brain injury or surgery.

**LO 14** Identify the brain structures involved in memory. (p. 267)

Researchers have identified many brain structures involved in the processing and storage of memory. The hippocampus is essential for creating new explicit memories, as are the temporal lobes and frontal cortex. Other areas, such as the cerebellum and amygdala, are integral in the processing of implicit memories.

**LO 15** Describe long-term potentiation and its relationship to memory. (p. 270)

Long-term potentiation refers to the increased efficiency of neural communication over time, resulting in learning and the formation of memories. The communication among neurons improves and strengthens, allowing for new skills to develop and become more natural. These new pathways explain how a skill, for example, is learned and thus becomes an implicit memory.

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**key terms**

- anterograde amnesia, p. 265
- chunking, p. 242
- distributed practice, p. 250
- echoic memory, p. 241
- effortful processing, p. 249
- elaborative rehearsal, p. 249
- encoding, p. 236
- encoding specificity principle, p. 255
- episodic memory, p. 246
- explicit memory, p. 245
- flashbulb memory, p. 246
- iconic memory, p. 241
- implicit memory, p. 246
- long-term memory, p. 239
- long-term potentiation, p. 270
- maintenance rehearsal, p. 242
- massed practice, p. 250
- memory, p. 235
- memory trace, p. 267
- misinformation effect, p. 261
- mnemonic, p. 247
- primacy effect, p. 254
- priming, p. 253
- proactive interference, p. 259
- procedural memory, p. 247
- recall, p. 253
- recency effect, p. 254
- recognition, p. 253
- relearning, p. 256
- retrieval, p. 236
- retrieval cues, p. 253
- retroactive interference, p. 259
- retrograde amnesia, p. 266
- rich false memories, p. 262
- semantic memory, p. 246
- sensory memory, p. 239
- serial position effect, p. 254
- short-term memory, p. 239
- storage, p. 236
- working memory, p. 243

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**test prep are you ready?**

1. You try to remember the name of a movie you watched last year, but struggle to recall it. When you do finally remember the film was *The Martian*, which memory process were you using?
   - a. short-term memory
   - b. sensory memory
   - c. encoding
   - d. retrieval

2. According to the levels of processing framework, there is a __________ that corresponds to the depth at which information is processed, as well as reflecting how durable and retrievable a memory may be.
   - a. hierarchy of processing
   - b. computer metaphor
   - c. method of loci
   - d. phonological loop
3. Using the partial report method, Sperling (1960) showed that participants could recall 76% of the letters briefly flashed on a screen. The findings from this study indicate the capabilities of:
   - a. eidetic imagery
   - b. iconic memory
   - c. depth of processing
   - d. the phonological loop

4. Miller (1956) reviewed findings from the Digit Span Test and found that short-term memory capacity is limited to between 5 and 9 numbers, that is, the “magical number seven, plus or minus two.” However, through the use of __________, we can improve the span of our short-term memory.
   - a. echoic memory
   - b. iconic memory
   - c. short-term memory
   - d. semantic memory

5. Baddeley and colleagues proposed that the purpose of __________ is to actively maintain information while the mind is performing complex tasks. The phonological loop, visuospatial sketchpad, central executive, and episodic buffer all play a role in this process.
   - a. eidetic imagery
   - b. working memory
   - c. short-term memory
   - d. semantic memory

6. In a classic study, Godden and Baddeley (1975) asked participants to learn lists of words under two conditions: while underwater and on dry land. Participants were better able to recall the information in the same context in which it was encoded. This finding supports:
   - a. the encoding specificity principle
   - b. Baddeley's working memory model
   - c. the information-processing model of memory

7. Your friend tells you she prefers multiple-choice tests because she is able to identify an answer when she sees it listed as one of the choices for a question. She is describing her __________, which is the process of matching incoming data to information stored in long-term memory.
   - a. relearning
   - b. recall
   - c. recognition
   - d. retrieval

8. __________ causes problems with the retrieval of memories because of information you learned in the past and __________ causes problems with retrieval due to recently learned information.
   - a. The recency effect; the primacy effect
   - b. The primacy effect; the recency effect
   - c. Proactive interference; retroactive interference
   - d. Retroactive interference; proactive interference

9. According to __________, memories can fade over time, becoming more vulnerable to new information. Thus, your memory of an event might include revisions of what really happened.
   - a. the information-processing model of memory
   - b. the levels of processing framework
   - c. Baddeley’s model of working memory
   - d. a reconstructionist model of memory

10. In studies by Loftus and colleagues, around 25% of participants are able to “remember” an event that never happened. This type of __________ shows us how the malleability of memory can influence recall.
    - a. hyperthymestic syndrome
    - b. rich false memory
    - c. proactive interference
    - d. serial position effect

11. In one study, Loftus and Palmer (1974) found that when they told participants two cars had “smashed” into each other, these same participants were more likely to report they had seen broken glass in a previously viewed film than participants who were told the cars had “hit” each other. This tendency for new and possibly deceptive information to distort one’s memory of a past incident is known as:
    - a. the misinformation effect
    - b. proactive interference
    - c. retroactive interference
    - d. the serial position effect

12. Traumatic experiences that are thought to be pushed out of consciousness are often referred to as __________ memories.
    - a. long-term
    - b. short-term
    - c. repressed
    - d. sensory

13. Retrograde amnesia is generally caused by some sort of trauma to the brain. People with retrograde amnesia generally cannot:
    - a. form memories of events that occur following the trauma.
    - b. access memories of events created before the trauma.
    - c. form semantic memories following the trauma.
    - d. use procedural memories.

14. __________ refers to the increased efficiency of neural communication over time, resulting in learning and the formation of memories.
    - a. Memory consolidation
    - b. Long-term potentiation
    - c. Memory trace
    - d. Priming

15. The __________ is essential for creating new explicit memories, but not implicit memories.
    - a. parietal lobe
    - b. amygdala
    - c. cerebellum
    - d. hippocampus

16. A friend says, “My grandmother has terrible short-term memory. She can’t remember anything from a couple of hours ago.” This statement represents a very common mistake people make when discussing memory. How would you explain this confusion about short-term memory versus long-term memory?

17. How are iconic memory and echoic memory different from each other?

18. How does working memory differ from short-term memory?

19. Create a mnemonic to help you remember the process of encoding, storage, and retrieval.

20. Imagine you are a teacher creating a list of classroom rules in case of an emergency. If you were expecting your students to remember these rules after only reading through them once, where in the list would you position the most important rules? Why?