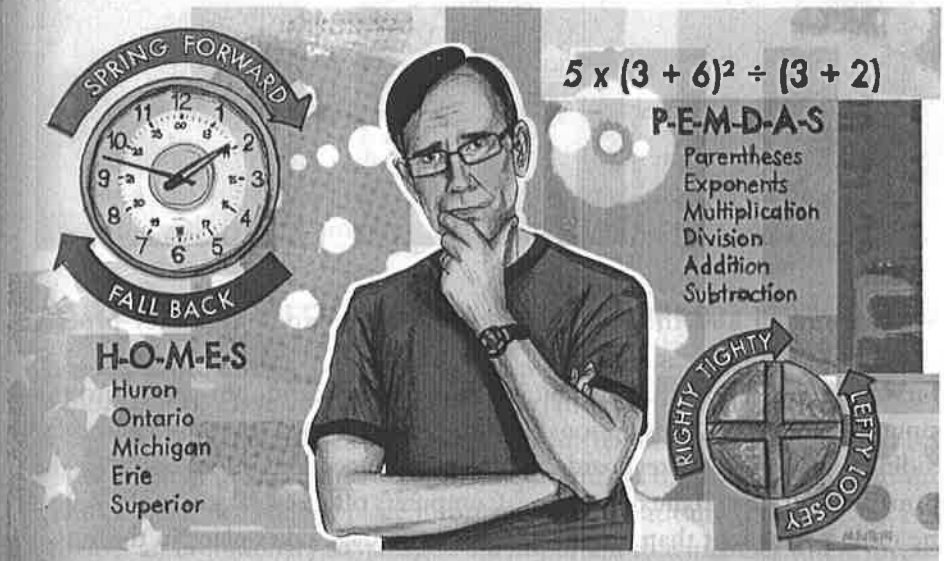
Information Processing

Module 23



I bet you've seen memory tricks like these. The technical term for them is *mnemonic devices*. As you will see in this module, they are an excellent strategy for encoding information into our memory. Because the information is so effectively encoded, retrieval of the memory is easy. This module is filled with practical information for improving your memory.

Learning Goals

23-1 Summarize the factors that allow for effective encoding of information into memory.

23-2 Explain the differences between sensory, short-term/working memory, and long-term memory.

23-3 Summarize the factors that influence what we can remember and what we forget.

Information processing enables memory, a cognitive skill so important that it's impossible to imagine life without it. Before leaving for school in the morning, I need to remember to let the dog out. I also need to remember to put the student papers I read last night into my briefcase and take some ground beef out of the freezer for tonight's dinner. As I sit here working, I can remember details from my recently completed weekend. On Friday evening, I had great fun playing pickleball with friends. My wife and I went to see a pretty good movie on Saturday. The football game I saw on television was close enough to hold my attention all the way to the end.

We rely on memory all the time, and not just for the details of our daily lives. I need to remember who I am and what I stand for. I need to remember the norms our society has developed—the "proper" rules for behavior: what to do with my trash, how to order a meal in a restaurant, which side of the hall to walk on, and a thousand other guidelines that let us coexist in a complex society. I also need to remember how to cook, how to reconcile my credit card statement, how to wash my clothes, and how to program the alarm on my cell phone. And though I am not consciously aware of it, I even need to remember the meanings of words in my language and the processes necessary for walking or standing upright.

In this module, we focus on memory, using an updated version of a classic information-processing model.[1] There are certainly differences between how a human brain works and how a computer works, but they both process information in three basic steps (see **Figure 23.1**):

1. **Encoding,** or getting information into the memory system
2. **Storage,** or retaining information in memory over time
3. **Retrieval,** or getting information out of memory storage

encoding The process of getting information into the memory system.

storage The retention of encoded information in memory over time.

retrieval The process of getting information out of memory storage.

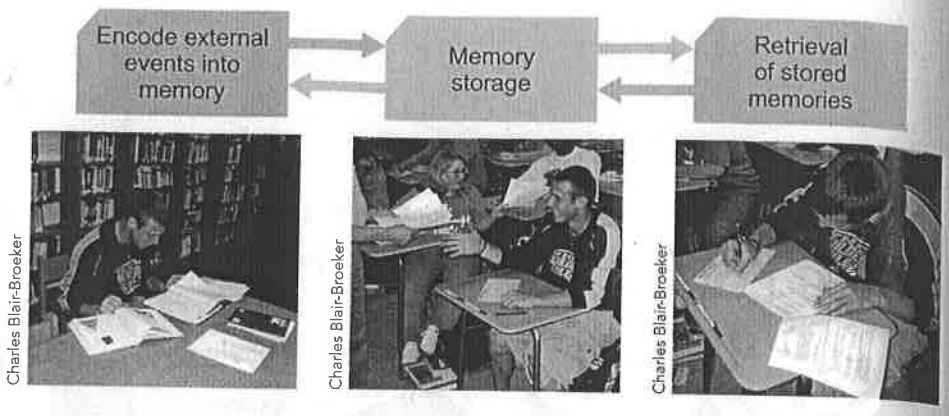


FIGURE 23.1
The Information-Processing Model of Memory
Students in my classroom demonstrate that memories are processed through three stages. Encoding brings information into the memory system. Storage allows us to retain the information over time. Retrieval brings the information back out of memory.

We can look at how these three steps work for computers as they process information.

First, nothing happens unless you can *encode* information, or get it into the computer. There are various options for doing this, but two common devices for encoding information are keyboards and Internet connections. Once encoded, the information must be retained in *storage.* Computers offer several kinds of storage, some more permanent than others. Temporary storage takes place in the active memory of the computer that keeps the various applications open on your screen. You know how temporary this memory is if you've ever briefly lost power while working on a project. More-permanent storage is available on the computer's drive. This storage can even survive the computer's "loss of consciousness" when it's turned off. Cloud storage is even more permanent—your work is still there even if the computer you did it on gets run over by a truck! But all this encoding and storage would be useless if you couldn't *retrieve* information from storage. If you're careful about setting up folders and subfolders, this can be a snap. If you're not careful, you can lose documents. You may know that you've stored your English paper, but if you can't recall what you named it or the folder in which you placed it, then you won't be able to retrieve it easily.

Humans also encode information. Instead of an Internet connection or keyboard, we use our senses to gather information. Then we must store the information, either temporarily or permanently. Finally, we must gain access to the memories we have permanently stored. Let's take a more detailed look at these three steps in the human system.

LIFE MATTERS
Exercise good study habits by making sure you pick a few 30-minute windows each week to quiz yourself on course material that you've previously learned. This will alert you to what you don't know (metacognition), and help you practice rehearsal so that you stay ahead of the forgetting curve.

Encoding

23-1 What are the factors that allow us to effectively encode information into our memory system?

Encoding is the process in which you move information—the raw material, the stuff that you will remember—into your memory system. Good students are invariably good encoders of information. Fortunately, we can control several factors that influence how well we encode information. In this section, we examine the following:

- The role of effort in encoding
- The effect of the order of the information on encoding, known as the serial position effect

- The significance of how you space out the rehearsal of the information to be encoded
- The huge contribution of the meaning of information to be encoded
- The effectiveness of encoding visual images
- The use of mnemonic devices, or memory tricks
- The importance of organizing information to be encoded

Have you ever noticed that committing items to memory sometimes takes a heck of a lot of work? That brings us to our first topic, the distinction between automatic and effortful processing of information.

automatic processing The unconscious and effortless process of encoding information such as space, time, and frequency.

effortful processing Encoding that requires attention and conscious effort.

rehearsal The conscious repetition of information.

Automatic Processing and Effortful Processing

Automatic processing is the unconscious process of encoding certain information without effort. Have you ever had the frustrating experience of taking a test and being able to remember exactly *where* in your textbook the information is but not being able to remember the more important bit of *what* the information is? That's because we encode place information automatically (probably because it provides an evolutionary advantage—it's important to remember where threats in the environment came from, for example). We also tend to encode information about time (you can remember what time your friend called) and frequency (how many times your brother interrupted you with questions while you were studying) automatically.

Well-learned information can be processed automatically. (Compare how easily you can process information in a video game that you have played hundreds of times with how difficult it was to keep track of everything going on the first few times you played.) Unfortunately, when you're trying to learn the content of this textbook, you don't usually automatically capture *what* is written there. To master that information, you must engage in **effortful processing,** encoding that requires attention and conscious effort (see **Figure 23.2**). Research indicates that some processing strategies are more effective than others, and the most important one seems to be **rehearsal,** the conscious and focused repetition of information.

Hermann Ebbinghaus taught us much of what we know about the importance of rehearsal (which is another word for practice). Ebbinghaus, a nineteenth-century German philosopher, wanted data to support his ideas about memory. To obtain those data, he spent a considerable amount of time memorizing lists of three-letter nonsense syllables. If this sounds like nonsense to you, keep in mind that Ebbinghaus wanted

LIFE MATTERS

We are not effective at multi-tasking or switch-tasking. 21% of teen drivers involved in fatal accidents were distracted by their cell phones. Paying attention to the road and texting a friend both require effort. Keep yourself and other drivers safe by putting the phone down while driving.

Bettmann/Getty Images

HERMANN EBBINGHAUS (1850–1909)
German philosopher who conducted pioneering memory studies.

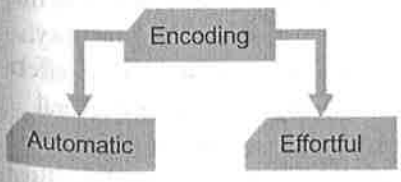


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FIGURE 23.2
Automatic Processing and Effortful Processing
Thanks to automatic processing, this student may be able to remember where in his textbook he found the information he needs to study with no effort. But he will have to pay attention and use effortful processing to encode the information he's trying to learn from the book.

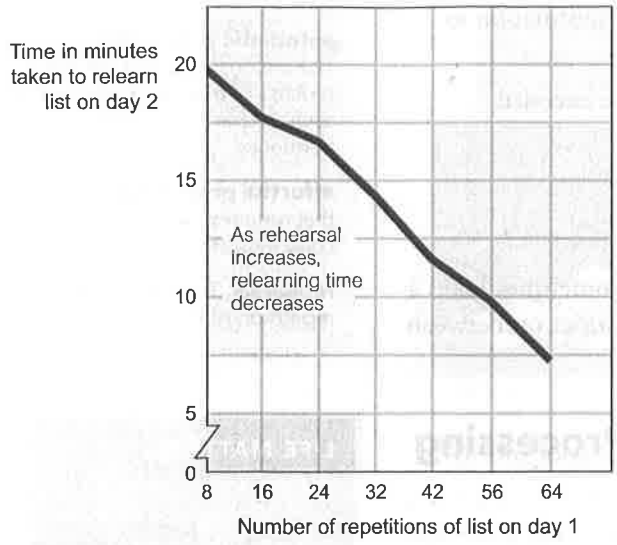


FIGURE 23.3
Rehearsal and Retention
Hermann Ebbinghaus discovered that the more times he rehearsed a list on the first day, the less time it took to be able to repeat the list with no errors on the second day. (Data from Baddeley, 1982.)

to memorize only unfamiliar items. His major conclusion? The more you rehearse, the more you retain (see **Figure 23.3**). Focused practice, indeed, does make perfect. In the years since Ebbinghaus conducted his research, psychological scientists have learned much more about rehearsal. One of the most important findings is that rehearsal that involves testing yourself over the material is particularly effective.[2–4] So, here's your first tip for becoming a good encoder: *The more time you invest in actively rehearsing and testing yourself over information, the more effective your memory will be.*

Another effective processing strategy is overlearning—continuing to rehearse information even after you have memorized it. Students who play musical instruments know they should continue to practice pieces that they can already play without error. And gymnasts know that they must continue to rehearse mistake-free routines to give their best performances in competition. Overlearning is just as important for course-related information. So, here's your second tip: *Continue to rehearse academic information even after you think you have it mastered.* This is one of the best ways to make sure the information is available under stressful test conditions.

Without question, then, rehearsal is important. It's not the only factor that influences encoding, however. Let's turn our attention to the serial position effect and see how the order of presented information affects encoding.

Serial Position Effect

serial position effect The tendency to recall the first and last items in a list more easily.

How many times have you taken a test in which you had to remember a list of items? Probably a lot. At such times, the **serial position effect**—the tendency to recall the first and last items on the list more easily—comes into play. Chances are good that you struggled most with recalling the middle items (see **Figure 23.4**). You may also have experienced the serial position effect if you were introduced to a dozen new people at a party. By the end of the evening, which ones were you most likely to remember? It's probably the folks you met first and last. Each of these conditions has its own term:

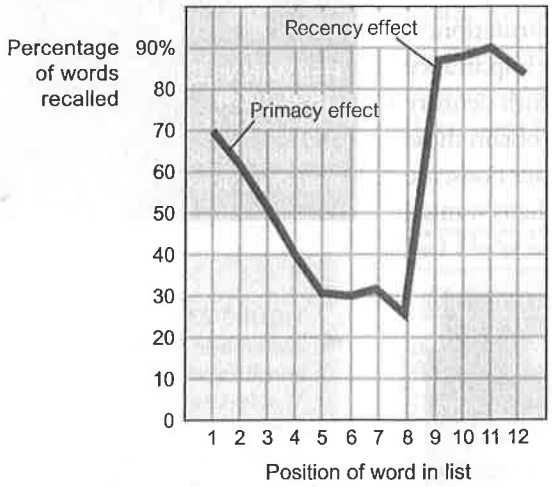


FIGURE 23.4
The Serial Position Effect
People given a list of items and later asked to recall the items had little trouble remembering the first few items (the primacy effect) and the last few items (the recency effect). The hardest items to recall are those in the middle. (Data from Craik & Watkins, 1973.)

- The *primacy effect* enhances our ability to recall items near the beginning of a list. We have more opportunities to rehearse those first items. Memory researchers who want to minimize the primacy effect may present the list of items quickly, thus eliminating the opportunity to rehearse between items.
- The *recency effect* enhances our ability to recall items near the end of a list. The most recent items are freshest in memory. Memory researchers who want to eliminate the recency effect will delay recall or distract the memorizer by asking several unrelated questions ("What is your zip code?") between presenting the final items and asking people to recall the list.[5]

Here is your third tip: *Devote extra rehearsal time to the middle of lists you must memorize.* However, it's not just the amount of rehearsal that's important. Our next topic shows that how you divide up the rehearsal matters, too.

Spacing of Rehearsal

The effectiveness of rehearsal depends on when you do it. More than 300 experiments on the spacing of rehearsal show *distributed rehearsal*—or spread-out sessions—works better than *massed rehearsal,* rehearsal packed together into fewer, longer sessions (cramming).[6] Consider the way performers practice. Do actors or musicians mass all their rehearsals for the week into a single, daylong session? No, because as the performers tire, additional rehearsal becomes less valuable. So, here's your fourth tip: *If you cram all your studying into one long session the night before an exam, then you will not encode the information as effectively as you would if you spaced your study time fairly evenly throughout the unit.* Even if you somehow manage to put in as many hours, you won't learn as much per hour. The research about distributed rehearsal is one of the most powerful arguments for the use of comprehensive final exams—reviewing the material from a course throughout the term enhances *lifelong* retention of the material.[7] And, speaking of final exams, there is evidence that if you continually quiz yourself on the material you are studying, the effectiveness of those distributed study sessions increases significantly.[8] By self-testing, you make sure you are actively involved with the material.

Now let's turn to one of the most important encoding factors. Once, when I was a high school junior, my English teacher made our class memorize a section of Chaucer's *Canterbury Tales* in its original Middle English. I had a horrible time with this task because I didn't know how most of these Middle English words translated into modern English. As we're about to learn, meaning matters.

Encoding Meaning

Rehearsal is central to encoding, but what's also important is how meaningful the information is. You might well think of rehearsal and how meaningful the information is as the twin pillars of encoding. If you're interested in cutting down the amount of time you spend in rehearsal (and what student isn't?), then your most effective option is to make the material meaningful, a process known as **semantic encoding.**

semantic encoding Encoding of meaning.

Research shows that when we encode according to meaning, we remember more effectively than when we encode either sounds *(acoustic encoding)* or images *(visual encoding).* In one experiment, researchers flashed words to participants and then followed with questions that led to semantic, acoustic, or visual processing of information (see **Figure 23.5**). For example, to make participants process acoustically, the researchers might ask whether the flashed word rhymed with another word. To promote semantic encoding, researchers would ask whether the flashed word would make sense in a particular sentence. The participants remembered better when they had encoded the material semantically.[9] We now know that each of these types of encoding uses a different part of the brain.[10]

An excellent way to enhance meaning is to use dual coding. This method relies on having the learner formulate ways to make information visual. This could involve creating a timeline, diagram, graphic organizer, or cartoon. Creating an image makes information more meaningful.

Ebbinghaus himself estimated that it was *10 times* harder to learn nonsense syllables than meaningful material. This is why it is wise to search for meaning. So, here is your fifth tip: *One good way to add meaning to material is to use the*

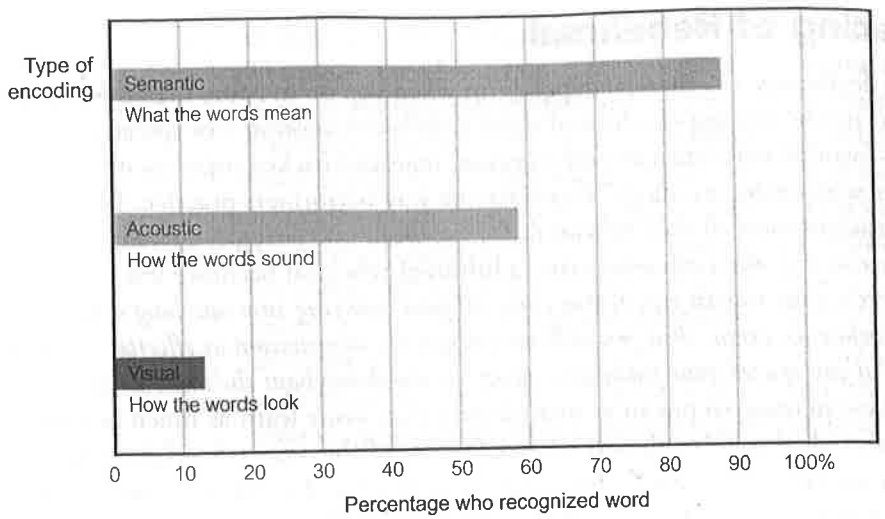


FIGURE 23.5 The Advantage of Semantic Encoding This graph shows the results of a study in which researchers flashed words and caused people to process the words according to their meaning (semantic encoding), sound (acoustic encoding), or image (visual encoding). They found that people were most likely to remember the words if they had considered their meaning. (Data from Craik & Tulving, 1975.)

Image Source/Alamy Stock Photo

Practice Makes Perfect! Whether in sports, music, or academics, more rehearsal leads to better performance.

self-reference effect by relating it to your own life. Physics students in my school spend a day each spring at the amusement park. The principles of physics that make the rides both exciting and safe are somehow more meaningful—and memorable—when you're twisting through space on the roller coaster. Of course, you don't have to go to the amusement park to take advantage of this. If you can think about and imagine such connections, then any material will be encoded and remembered more effectively.[11] This is especially true in Western cultures like the United States, where there is a strong emphasis on the importance of the individual.[12] And meaningful connections are particularly easy to find in a psychology course because the subject matter—behavior and mental processes—relates to *you.*

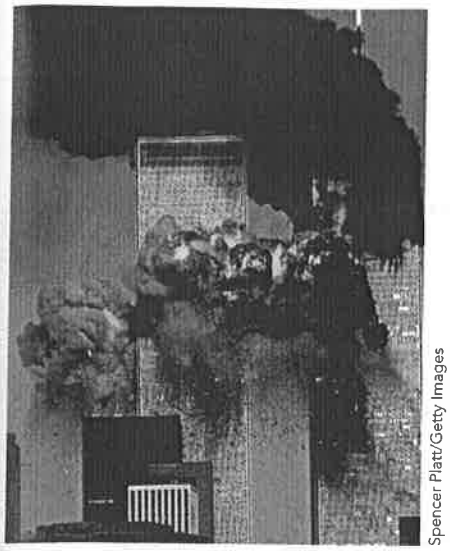
When it comes to encoding, the old expression that a picture is worth a thousand words holds a great deal of truth. Can you picture the Rocky Mountains? The White House? Jennifer Lawrence? Let's look at the relationship between images and encoding.

LIFE MATTERS

Do you wait until the last minute to study for a test? Distributed practice is much more effective than cramming, but if you must cram, do it the night before an exam rather than the day of. REM is an important process in embedding long-term memories, and you will be more likely to remember information after a night's rest.

Encoding Imagery

Encoding visual images is relatively easy. Visual images tend to stick in our minds, as you well know if you've ever struggled to rid your mind of the image of an unpleasant event. If you've seen photos or videos of the 9/11 collapse of the World Trade Center towers, the raising of the flag over Iwo Jima in World War II, or Neil Armstrong walking on the surface of the moon in 1969, you know how memorable these iconic images are. Images of positive personal events especially tend to stick in our minds. Do you have positive images of your elementary school days? For many of us, these happy snapshots overwhelm the less-pleasant aspects of grade school. The third-grade make-your-own-sundae party remains, but the day you suffered through class with a stomach ache does not. This tendency to encode images of the high points while letting the tedious or less joyous moments pass causes us to recall events—like elementary school—more positively than we actually felt about them at the time. Just think, this *rosy retrospection*[13] will probably apply one day to your high school memories! The tests, relationship hassles, and scheduling difficulties will likely be overwhelmed by more pleasant images.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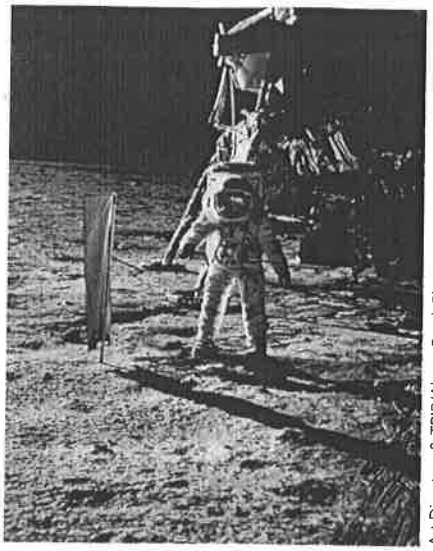
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The Power of Images These images of historic events are memorable. Once you've seen them, you're not likely to forget them.

Do you like tricks? Mnemonic devices can influence the encoding of information, too.

Mnemonic Devices

Which way do you set your clock for daylight saving time? To come up with the right answer, I remember "spring forward". When using a screwdriver, it's righty-tighty, lefty-loosey. I do well naming the Great Lakes, too, because of the acronym HOMES—Huron, Ontario, Michigan, Erie, and Superior. These are examples of **mnemonic devices** (pronounced nih-MON-ik), a formal term for memory tricks. If you recall that we encode visual images fairly easily, then you'll understand why so many of these memory tricks rely heavily on imagery. The method of loci and the peg-word system are two of the best-known image-based mnemonic devices.

mnemonic [nih-MON-ik] device A memory trick or technique.

Have you ever heard a speaker preface major points of a talk with phrases like "In the first place, I'd like to discuss . . ." or "In the second place, let's shift our attention to . . ."? Where are these "places" the speaker is referring to? They are in the imagination, and they relate to an old speaker's technique for remembering major points in the days before teleprompters. This mnemonic device is called the *method of loci:* You associate items you want to remember with imaginary places. Suppose I want to remember to remind my classes of an upcoming assignment for a day when I'll miss class because of a teacher's conference. To use the method of loci, I might imagine my living room, with student papers strewn all over my couch, waiting to be corrected. I could "see" myself trying to enter the room and tripping over a suitcase sitting by the door. Later, in school, I would return to this scene in my mind. The couch would remind me of the assignment, and the suitcase would remind me of the trip.

Theresa McCracken/ www.CartoonStock.com

The Mnemonic Plague.

Another mnemonic device that depends on imagery is the *peg-word system,* in which you associate words you want to remember with a list of peg words you have already memorized. To use this memory trick, you would learn a set of peg words—words or phrases on which you can hang the items you want

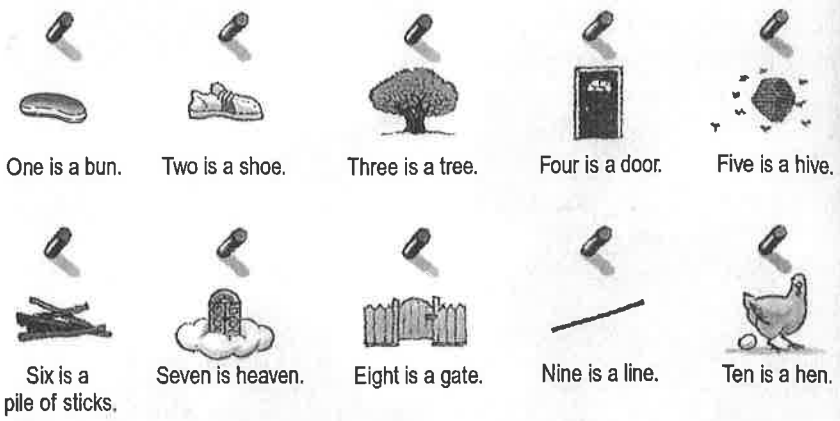


FIGURE 23.6
A Simple Peg-Word System
Learn these 10 "pegs," and you can use them to remember any list of 10 items by creating vivid associations between the items and the pegs. Research shows that a list learned this way can be remembered in any order with few errors (Bugelski et al., 1968). Notice that the pegs (*bun, shoe,* and so on) rhyme with the numbers (*one, two,* and so on)—a mnemonic device in its own right.

to remember (see **Figure 23.6**). The more striking and unusual the image, the less likely you are to forget the item. For example, assume that the first item I want to remember is carrots, and my peg for Item 1 is *bun.* To come up with a vivid image linking carrots and buns, I could imagine a steaming hot carrot in a hot dog bun and see myself adding ketchup, mustard, onions, and relish before taking a big, delicious bite. Then I'd associate my second item with the peg *shoe,* and so on. You are right if you're thinking this is a lot of effort, but memories encoded with the peg-word system can last a long time. When I use it to teach a 10-item list to my students, they can usually recall the list perfectly more than a month later. So, here's your sixth encoding tip: *Memory tricks like the method of loci and the peg-word system can create vivid images that you won't easily forget.*

Have you ever wasted time because you could not find your keys, your homework assignment, or your flip-flops? Just as getting organized is important in day-to-day life, it's important for encoding information, too.

Organizing Information

I happened to stumble upon a NASCAR race on television the other day and was amazed by the efficiency of the pit crews. They were able to accomplish more in a few seconds than my local mechanic can do in an hour. Many factors help explain this, not the least of which is organization. Each member of the pit crew plays a meaningful role in a highly organized structure designed to produce maximum efficiency.

chunking Organizing information into meaningful units.

Here's your seventh tip for becoming a successful encoder: *You can encode more efficiently if you take a few moments to organize your information first.* Organizing information into meaningful units is called **chunking.** You can encode many more letters if they are organized into meaningful words and sentences than you can if they are just randomly grouped (see **Figure 23.7**).

ROW 1	RNN TYW KTYU ACDF OAHNSOO RTA UO UCR OYO
ROW 2	ASK NOT WHAT YOUR COUNTRY CAN DO FOR YOU

FIGURE 23.7
Effectiveness of Chunking
Give yourself 10 seconds to learn the letters in row 1. How well did you do? Now try row 2. Did you do any better? The identical letters appear in both rows, but they are easier to encode if they are chunked, or organized into meaningful units—in this case, into words and then into a meaningful sentence.

Organizing information into a *hierarchy* is another effective encoding technique. Hierarchies are organizational systems that focus on the relationships between pieces of information. The most familiar example of a hierarchical organization is an outline, which you've probably done for papers or other assignments. By indenting subpoints beneath main points, you get a sense of how each piece of information relates to the rest of the information. Chemistry's periodic table of elements is another example of hierarchical organization. It is so central to the field that it hangs on the wall of every chemistry classroom and is

printed inside the cover of every chemistry textbook. Each row and column provides specific meaning to help the user know how the elements relate to one another.

One way to think of encoding is to consider whether your strategy is *shallow* or *deep*. Deep encoding involves processing information in a way that is rich and multifaceted. Adding emotion, imagery, personal connections, and organization are all ways to encode more deeply. The more deeply you encode, the more effectively you encode, so strive to create as much depth as you can when you are faced with memory tasks. Avoid shallow encoding as you review and master the tips on becoming a better encoder. The list is summarized next.

LIFE MATTERS

Effective learning strategies can be counterintuitive. Continuously rereading your textbook feels like it is effective, and yet this shallow processing of information does not yield increased results. Now that you know, don't waste your time with ineffective strategies.

Tips for Becoming a Better Encoder

The goal of positive psychology is to achieve optimal human functioning. A good memory helps you function better and make fewer mistakes in virtually every aspect of day-to-day life. It's important to realize that almost everyone can improve memory skills by applying the principles of encoding that we have discussed in this module.

Here, in one place, are the seven encoding tips that have been presented in this module. Think about each one in relation to your own study skills. Are there a couple you can focus on to improve your memory and become a better student?

1. *Rehearse*—The more time you invest in rehearsing, and especially testing yourself over information you're trying to learn, the more effective your memory is going to be.
2. *Overlearn*—Continue to rehearse academic information even after you think you have it mastered.
3. *Overcome the serial position effect*—Devote extra rehearsal time to the middle of lists you must memorize.
4. *Benefit from the spacing effect*—If you cram all your studying into one long session the night before an exam, you will not encode the information as effectively as you would if you spaced your study time fairly evenly throughout the unit.
5. *Take advantage of the self-reference effect*—One good way to add meaning to material is to relate it to your own life.
6. *Use mnemonic devices*—Memory tricks like the method of loci and the peg-word system can create vivid images that you won't easily forget.
7. *Chunk material or arrange it in a hierarchy*—You can encode more efficiently if you take a few moments to organize your information first.

MAKE IT STICK!

1. The _____ effect enhances encoding by making information personally relevant.

2. True or False: Frequent short study sessions are more effective than a few lengthy study sessions.

3. The ability to remember the first and last items on a list more readily than the ones in the middle is called the _____ effect.

a. mnemonic device
b. semantic encoding
c. serial position
d. distributed rehearsal

4. Associating items you need to remember with imaginary places is called the _____.

5. Which of the following does NOT enhance deep encoding?

a. Imagery
b. Repetition
c. Self-referencing
d. Mnemonic devices

Storage

23-2 What distinguishes sensory, short-term/working, and long-term memories?

Storage is the retention of information, the very core of memory. Humans have three distinct storage systems, each with a different degree of permanence. We will deal with them in order from least permanent to most permanent: sensory memory, short-term/working memory, and long-term memory. Next, we will look at how your brain stores long-term memories and then explore explicit and implicit memories.

Sensory Memory

Our senses are constantly bombarded with sensory input. Consider how many objects are in view right now. If you're in a classroom, there are undoubtedly displays on the wall, scenes visible through windows (if you're lucky enough to have windows in your room), and people to look at. Each of those people offers much to see—facial features, hairstyle, items of clothing, jewelry, and so forth. And that's just visual input. What can you hear right now? Is anyone talking? Is there machinery operating? Is there music in your environment? Even a quiet environment might include the rustling of papers or the gentle sound of someone breathing. Add to this the smells, tastes, touches, and internal feedback on balance and position that you receive from your body, and it becomes obvious that we gather more information at any instant than we can possibly cope with or hope to use. **Sensory memory** is the brief, initial encoding of sensory information in the memory system.

sensory memory Brief, initial coding of sensory information in the memory system.

We can hold visual information in sensory memory for less than half a second, just long enough to make a decision about its importance. We do this while it is in the *iconic store.*[14] (Think of the little pictures that constitute computer icons to remember that *iconic* is visual.) It is the iconic store that helps us hold one image in our visual field until another image replaces it. We hold auditory, or sound, information in sensory memory for perhaps 3 or 4 seconds, in the *echoic store.*[15,16] (Think of the word *echo* to remember that *echoic* is acoustic.) Have you ever been spacing out in class and had a teacher ask, with an irritated tone, "What did I just say?" Did you notice that you can generally retrieve that information, even though you truly weren't paying attention? Thank your echoic store for this ability.

Short-Term/Working Memory

short-term/working memory The part of your memory system that contains information you are consciously aware of before it is stored more permanently or forgotten.

Your **short-term/working memory** is more permanent than sensory memory. This part of your memory system contains information you are consciously aware of before it is either stored more permanently or forgotten. Short-term memory is referred to as working memory to emphasize the active auditory processing and visual processing that occur there.[17] In this way, it is similar to the active memory on your computer that allows you to manipulate and use several applications at once.

Sensory memory is brief but huge. Short-term memory is far more limited because our consciousness itself is limited—we can attend to only a few things at one time. How many? George Miller established that short-term memory can maintain roughly seven chunks of information, or—as his classic research article put it in the title—"The Magical Number Seven, Plus or Minus Two."[18] In other

words, most people can handle somewhere between five and nine chunks of information at one time. When my co-author spells his name for other people, he can run it all together: E-r-n-s-t. With a five-letter name, people have no problem maintaining the whole thing in their short-term memory at once. When I spell my name for others, however, I can't just run the letters together. *Blair-Broeker* contains 13 characters, including the hyphen, and that is enough to overwhelm short-term memory. I have to pause at least a couple times as I spell it if there is to be any hope of the other person getting it down correctly. Newer research indicates that the magical number may in fact be closer to four items in most cases.[19,20] The point is that we can only work with a relatively small amount of information at any one time. Notice that the capacity of short-term/working memory is a limited number of *chunks,* but you can hold chunks almost as easily as individual items. Holding five words in short-term memory, for example, means that you are likely holding more than five syllables and a lot more than five letters. Chunking is an effective technique not only for encoding but also for increasing the capacity of short-term memory.

What about the duration of short-term memory—how *long* can we retain information in this portion of our memory? About as long as you keep rehearsing it. If you meet a new and interesting person at a party, you will retain the person's name as long as you keep repeating it to yourself. But what if you become distracted? How long will the name stay? To answer this question, researchers presented participants with short, three-consonant groups of letters to remember. They then distracted the participants by giving them an arithmetic task that prevented rehearsal. As the results show (see **Figure 23.8**), short-term memory is indeed short term. Even though people had to remember only three consonants, these items disappeared from memory in less than 20 seconds when rehearsal was prevented.[21]

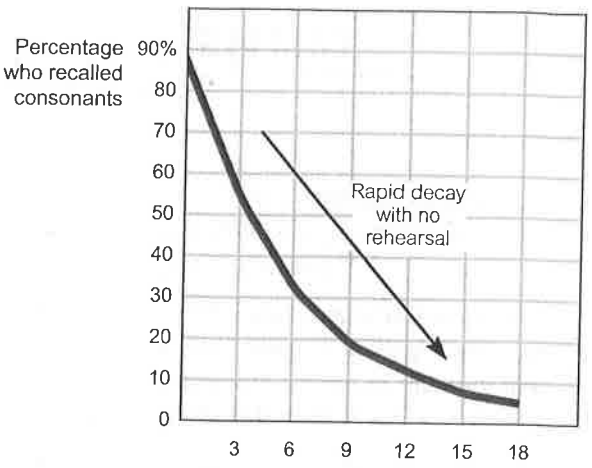


FIGURE 23.8
How Long Does Short-Term Memory Last?
As this graph shows, when people are not allowed to rehearse, short-term memory decays rapidly. Within a few seconds, most people are unable to recall three consonants. By the time 20 seconds have passed, nearly everybody has lost their memory of the three consonants. (Data from Peterson & Peterson, 1959.)

Short-term memory, with its limited capacity and short duration, is like a stovetop on which you're preparing your dinner. Having only four burners limits the number of dishes and volume of food you can cook. You also must pay active attention to the food you're preparing if you're going to avoid ruining the meal or burning down the house. All the rest of the food stored in your cupboards, refrigerator, and freezer—the food you don't need to pay attention to—represents our next topic: long-term memory.

Long-Term Memory

Long-term memory is the relatively permanent and limitless storehouse of the memory system. It can hold memories without conscious effort. Remember the computer analogy here. Short-term memory is like the active memory on your computer that allows you to deal with the various projects on your screen. Constant power (attention) is necessary to maintain short-term memory. What happens to your work if the power blinks off? It's gone! As a result, most of us have learned to save our work frequently (or rely on software that does it automatically). This means we make a more permanent copy of the project on the computer's hard drive or in the Cloud—methods that will retain the information even when the machine is turned off.

long-term memory The relatively permanent and limitless storehouse of the memory system.

Similarly, we can file information in our long-term memory and have it stay there without paying attention to it. It's available (we hope) when we want it. You probably have not been thinking about these bits of information, but I'll bet you can easily retrieve your zip code, the name of your English teacher, details of how you spent last New Year's Eve, and countless other facts and events that you have encoded and stored in long-term memory. Note that you effectively encoded these pieces of information either because you rehearsed them frequently or because they held personal meaning for you—two of the factors we identified as crucial when we discussed encoding. And now they are permanent residents in your long-term memory storehouse.

There are huge individual differences in the capabilities of long-term memory. Brain damage can destroy a person's ability to store memories for the long term. This was the case with a patient known as H.M. (identified as one Henry Molaison after his 2008 death), whose memory was damaged as an unfortunate side effect of brain surgery. He was able to retrieve long-term memories that were in place at the time of the surgery but could not store memories of any event after it. A researcher who worked with him for over 40 years after his memory was damaged said, "I've known H.M. since 1962, and he still doesn't know who I am."[22]

On the other end of the scale is the case of a Russian journalist known as S, later identified as Solomon Shereshevsky, who could effortlessly recall tiny details of events that had occurred years earlier. For example, he could recall strings of up to 70 digits that he had heard presented just one time. Once learned, he could perfectly recall the numbers even years later, along with details like the clothes worn by the individual who presented the numbers.[23] Perhaps even more amazing is the case of Akira Haraguchi, who recited from memory the first 100,000 digits of pi correctly on October 3 and 4, 2006.[24] Some people also seem to have a remarkable ability to recall their personal history, as you can see in Thinking Like a Psychological Scientist: What Were You Doing on November 4, 2008?

flashbulb memory A vivid, clear memory of an emotionally significant moment or event.

ROBERT J. ERWIN/Science Source

Clark's Nutcracker Do you ever have trouble remembering where you left your psychology book or your wallet? Compare your memory to that of the Clark's nutcracker. It can remember up to 6000 places where it has stored seeds for the winter (Shettleworth, 1993).

Long-term memory is as expansive as short-term/working memory is limited. What is its duration? Nobody knows for sure, but it's clear that humans can maintain memories for about a century. (Are you willing to trust your computer's hard drive to last that long?) Short-term memory can generally hold four to seven chunks. What's the capacity of long-term memory? Again, nobody knows. Like a sponge with unlimited capacity, your long-term memory can always absorb more, even on days when you feel you can't possibly take in even one more piece of information.

One especially interesting kind of long-term memory is **flashbulb memory,** a vivid memory of an emotionally significant moment or event. I have lots of these: driving home in my first car (a used powder blue 1965 Mustang GT); the sunshine briefly breaking through in the middle of our outdoor wedding; and being left in the hallway as they wheeled my wife in for an emergency cesarean section on the night our son Carl was born. Sometimes flashbulb memories center on a shared event. People in their 60s and older probably recall with amazing (but not necessarily accurate) detail what they were doing when they heard the news of the assassination of President John F. Kennedy. People alive at the time probably have flashbulb memories of the explosion of the space shuttle *Challenger* or of the September 11, 2001, terrorist attacks on the World Trade Center. For many, vivid memories of Hurricane Harvey will last a lifetime.

THINKING LIKE A PSYCHOLOGICAL SCIENTIST

What Were You Doing on November 4, 2008?

What if you couldn't forget? What if every detail of every day of your life was accurately stored in your memory? For example, what if you could accurately recall that Barack Obama was elected president on November 4, 2008, and what the weather was like on that day (and the day before and the day after)? And you could also recall what you were wearing that day, and what you ate for dinner, and a conversation you had with your mom about a neighbor's birthday, and the silly joke your math teacher told during second period, and how much you paid for the shoes you bought in the afternoon? What if, in fact, you could correctly answer any question put to you about anything you experienced that day (or any other day)?

Amazingly, there are such people, and they have recently captured the attention of researchers interested in their *highly superior autobiographical memory* (HSAM).[25] James McGaugh, Larry Cahill, and their colleagues at the University of California at Irvine were intrigued when McGaugh received an out-of-the-blue e-mail from a woman named Jill Price:

> I am thirty-four years old and since I was eleven I have had this unbelievable ability to recall my past, but not just recollections. My first memories are of being a toddler in the crib (circa 1967). . . . [However,] I can take a date, between 1974 and today, and tell you what day it falls on, what I was doing that day. . . . [If] anything of great importance (. . . The *Challenger* Explosion, Tuesday, January 28, 1986) occurred on that day I can describe that to you as well.[26]

McGaugh and Cahill were skeptical but agreed to meet with Ms. Price. Years of testing convinced them they were dealing with a form of memory that had never been identified before. Even people like the Russian journalist described earlier lacked the comprehensive, day-to-day recall that Ms. Price has repeatedly and reliably demonstrated. She has no special skill at memorizing poems or baseball statistics or the elements of the periodic table, but the details of her life, even the seemingly trivial ones, have remained with her for decades.

And she is not the only one. McGaugh and Cahill have now identified over 50 people with highly superior autobiographical memory, including actress Marilu Henner.[27] This form of memory is obviously not common, but we really do not know yet how many people possess it. They do not seem to be above average in intelligence, nor do they excel at other aspects of memory—only at accurately remembering details of their personal lives. More importantly, we don't know how the brains of these extraordinary individuals accomplish it. They have identified some ways in which their brains are different, and there are some trait differences between the super-rememberers and control groups, but they really don't know if the differences are the causes of their memory skills or the result of them.[28]


Dan Tuffs/Getty Images


Chris Pizzello/AP Images

Highly Superior Autobiographical Memory School administrator Jill Price and actress Marilu Henner live very different lives, but they have one remarkable thing in common: Each can remember virtually every detail of every day of her adult life. Studying them and other individuals with this type of super memory may increase our understanding of how memory works.

(*Continued*)

THINKING LIKE A PSYCHOLOGICAL SCIENTIST (Continued)

McGaugh, Cahill, and their colleagues are memory experts. Now, because of an unexpected e-mail message, they are exploring the hows and whys of a previously unknown phenomenon. We do not know what they will find, but we do know that the path they have started down is a fascinating—and memorable—example of the process of scientific discovery.

THINK ABOUT . . . Psychological Science

1. What is superior autobiographical memory?
2. How could you verify that someone who claimed to have superior autobiographical memory was telling the truth?
3. Would you want to have superior autobiographical memory? What are some of the benefits and drawbacks?

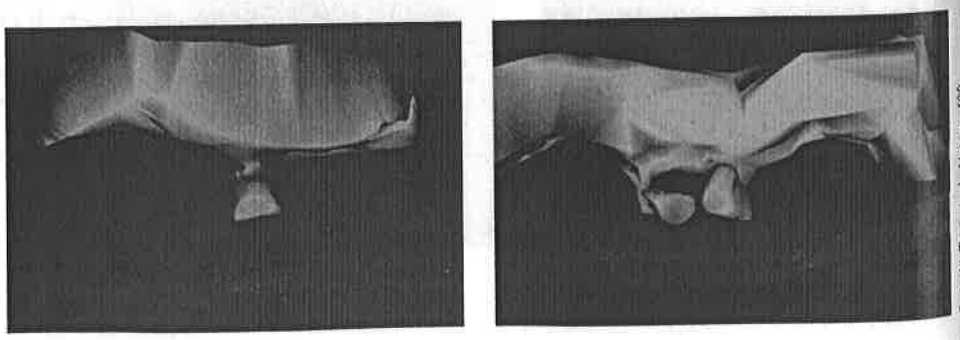
Memory and the Brain

How, exactly, does the brain go about storing long-term memories? This mystery has occupied scientists for decades, but in the past several years, researchers have uncovered some important clues. We now know that our brain does not function like a tape recorder, holding permanent, accurate records of every experience, ready to be played back if the right button is pushed. Current memory research indicates that memories are constructed from myriad bits and pieces of information.[29,30] Our brain *builds* our memories, just as you would assemble a jigsaw puzzle. When pieces are missing, we invent new ones to fill in the spaces. Because of this, some of our memories are accurate and others are way off.

long-term potentiation
An increase in a synapse's firing efficiency that occurs when the sequence of neurons that represents a particular memory fires repeatedly; believed to be the neural basis of learning and memory.

Another important clue to how memories are stored is that each memory appears to activate a particular specific pattern of firing in brain cells—neurons. The key to the process lies in the synapses that form the connecting points between the neurons. As the sequence of neurons that represents a particular memory fires repeatedly, the synapses between these neurons become more efficient, a process known as **long-term potentiation** (see **Figure 23.9**). Learning and memory stimulate the neurons to release chemicals (primarily the neurotransmitter serotonin) at the synapses, making it easier for the neurons to fire again in the future.[31,32] The tracks formed in your brain are almost like a trail blazed through deep snow from a cabin to the woodpile. With each repeated trip, the trail becomes easier to follow.

The concept of long-term potentiation helps explain several other memory phenomena. A variety of things, including a blow to the head, can disrupt neural function and the formation of new memories. This is why football players who have suffered concussions may have trouble remembering the play during which the injury occurred.[33] Drugs can also enhance or disrupt memories by



From N. Toni, et al., Nature, 402, Nov. 25, 1999. Dominique Muller

FIGURE 23.9
Growing a Memory
These two electron microscope images show one way that long-term potentiation makes a synapse more efficient. The left image, before long-term potentiation, shows only one receptor site (gray shows the receiving neuron). The right image shows two receptor sites. This dual target increases the likelihood that a message from the sending neuron will make it across the synapse to the receiving neuron. The growth of the second site is an indication that something may have been learned and remembered.

interacting with the neurotransmitters necessary for long-term potentiation. Alcohol is one such drug, which accounts for the alcohol-induced memory blackout that often accompanies a night of heavy drinking.[34]

Stress hormones also affect memory. Do you think they disrupt or enhance the ability to form long-term memories? Here's a hint: Stress is often the body's response to danger. It is important that we retain details of dangerous situations so that we can protect ourselves in the future. It's not surprising, then, that stress enhances memories. The hormones tell your body that something significant is happening, and they trigger biological changes that stimulate the formation of memories. People given a drug to block the effect of hormones in a stressful situation tend to remember fewer details of an upsetting story than their counterparts who did not receive the drug.[35] The part of the brain that processes stress-induced emotion activates the region responsible for forming memories and enhances its ability to function.[36,37]

Yellow Dog Productions/The Image Bank/Getty Images

Stress and Memory
Stressful events, such as this car accident, stimulate the release of stress hormones that enhance the formation of memories. These drivers are not likely to forget this day. Such memories may help encourage defensive driving in the future.

Explicit and Implicit Memories

Let's examine one last aspect of long-term memory. There are many types of memories, but one major division separates explicit memory from implicit memory (see **Figure 23.10**). **Explicit memory** is what we normally think of when we think of memory: the recall of facts and experiences. At what temperature does water freeze? Where did you eat dinner last night? What is your mother's middle name? Answering

explicit memory The memory of facts and experiences.

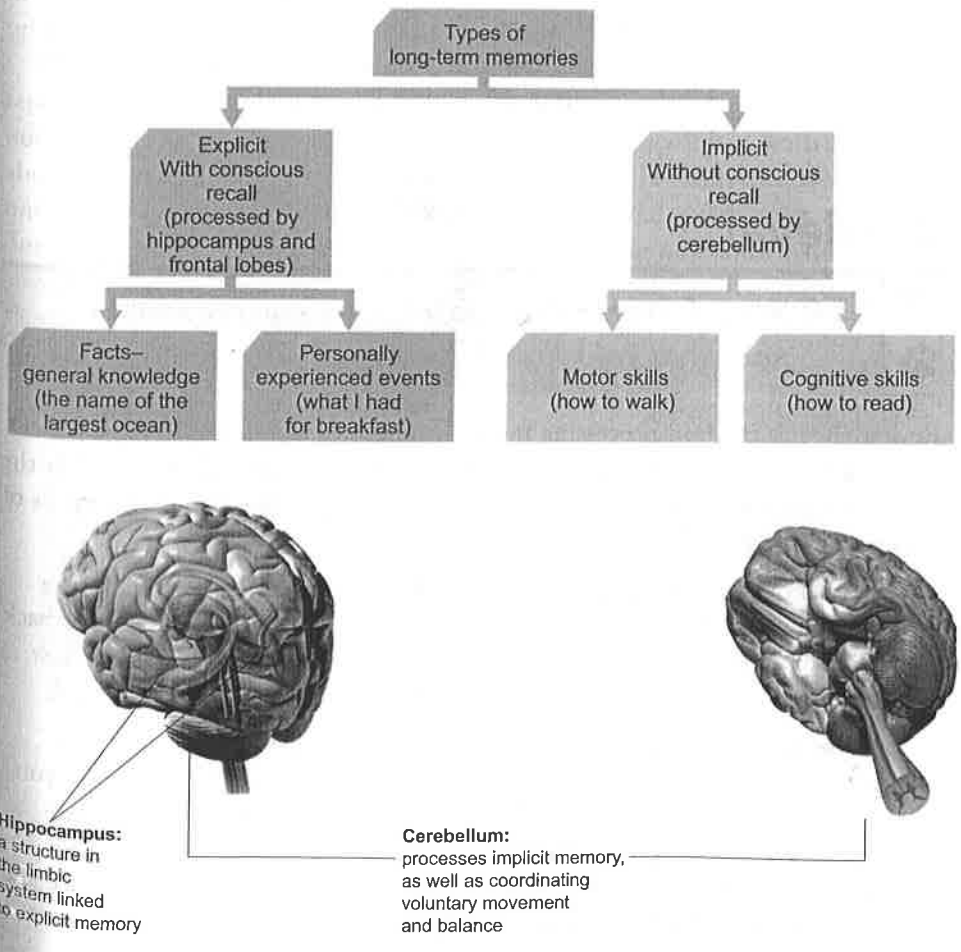


FIGURE 23.10
Explicitly or Implicitly Remembered?
Long-term memories can be classified as either explicit or implicit. These two types of memories are processed by different parts of the brain. Explicit memories of facts and experiences are processed through the hippocampus, a part of the limbic system deep in the center of the brain. Implicit memories for procedures and skills, however, are processed by the cerebellum, a structure at the bottom rear of the brain.

implicit memory The memory of skills and procedures.

all these questions requires a conscious effort to retrieve and state information. **Implicit memory** is the recall of skills and procedures, like walking. It requires no such conscious effort. You don't have to think about how to ride a bicycle before pedaling off. Nor do you have to think about how to read or how to button your shirt. Your ability to perform all these tasks depends on memory, but it is implicit, not explicit.

Explicit memory and implicit memory appear to be entirely different systems, controlled by different brain parts. Explicit memories are processed through the *hippocampus,* a small structure located in the central region of the brain, and the prefrontal cortex, the most forward part of the frontal lobes.[38,39] Implicit memories are processed through other parts, including the *cerebellum,* the rounded structure at the bottom rear of the brain (see Figure 23.10). Odd things can happen because of this split. A man who experienced damage to the hippocampus, for example, would be unable to form new explicit memories, but his ability to form implicit memories would remain intact. What would happen if he went to play golf on the same course each day? He would have no explicit memory of the course—it would seem like a new place every time. His scores, however, would gradually improve over time because his implicit memories would allow him to get better at golf as he continued to practice.

MAKE IT STICK!

1. What memory storage system holds the information you are thinking about right now?
   a. short-term/working memory
   b. sensory memory
   c. long-term memory
   d. flashbulb memory
2. An increase in a synapse's firing efficiency that seems to represent how the brain forms memories is called _____.
3. True or False: Some people have demonstrated an ability to accurately recall tens of thousands of numbers they have memorized previously.

Retrieval

23-3 What factors influence what we can remember and what we forget?

Review the information processing model for memory illustrated in **Figure 23.11**. We will now examine the final step of the model—retrieval. Retrieval is the process of getting information out of memory storage. The two major forms of retrieval are recall and recognition:

recall The type of retrieval in which you must search for information that you previously stored, as on a fill-in-the-blank test.

recognition The type of retrieval in which you must identify items you learned earlier, as on a multiple-choice test.

- **Recall** is the type of retrieval we usually think of as memory—searching for information that was previously stored. In recall, we are calling a memory back into conscious awareness. This is the literal meaning of the word *re-call.* Test makers use fill-in-the-blank, short-answer, and essay questions to tap recall.
- **Recognition** is a type of retrieval in which you must identify items you previously learned. Recognition is an easier process than recall because you only need to identify information. You may struggle to describe an individual you witnessed committing a crime (recall), yet have little trouble picking the person out of a police lineup (recognition). Multiple-choice and matching questions often test recognition.

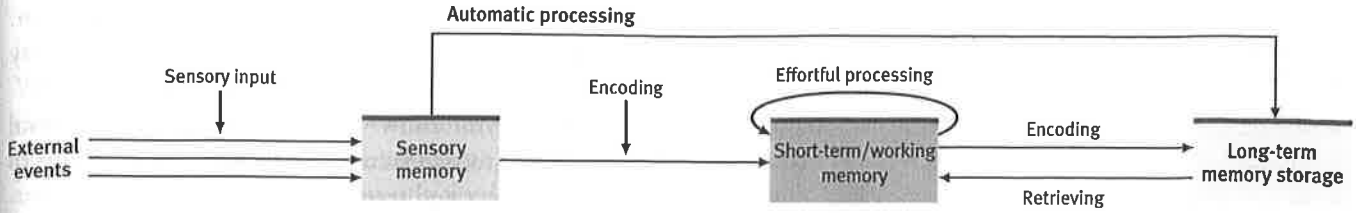


FIGURE 23.11
Information Processing Model
This figure provides a nice visual review of the information-processing model. Automatic processing can take place without effort. When effort is required, it occurs in short-term/working memory, the part of the system that involves conscious awareness. From short-term/working memory, information can be moved into and back out of long-term memory.

How do we get to the memories we need to retrieve? We follow pathways, often multiple pathways, that lead to the memory. When I need to contact a friend, I can do so by hopping in the car and driving to her house. If I'm less rushed, I can walk over. I can also text her, call her on the phone, find her on Facebook, or send a message via a mutual friend who I know will see her before I do. The point is, I have lots of ways to reach her. Likewise, there are many pathways I can follow to retrieve a memory. I can connect to a memory of, say, Mount Rushmore by remembering a family trip, by thinking of a TV show I might have seen, or by seeing a photo in a magazine. In each case, my memory of Mount Rushmore is primed, or triggered, by a memory retrieval cue (see **Figure 23.12**).


Courtesy Randal Ernst


Courtesy Charles Blair-Broeker

High School Days
Here is how my co-author and I looked when we were your age. Our present students might have difficulty identifying us, but our high school classmates would probably have no trouble.

Memories weave a web of neural pathways inside the brain, and retrieval cues send us down one pathway or another in our search for memories. Have you ever noticed that the more you know about a subject, the easier it is to learn even more about it? Learning and retrieval build on each other. For example, if you know only one or two isolated facts about how the U.S. federal government works, you don't have much of a framework upon which to hang new information, but if you already know about the Constitution, the three branches, the role of the civil service, significant Supreme Court decisions, and close presidential elections, it

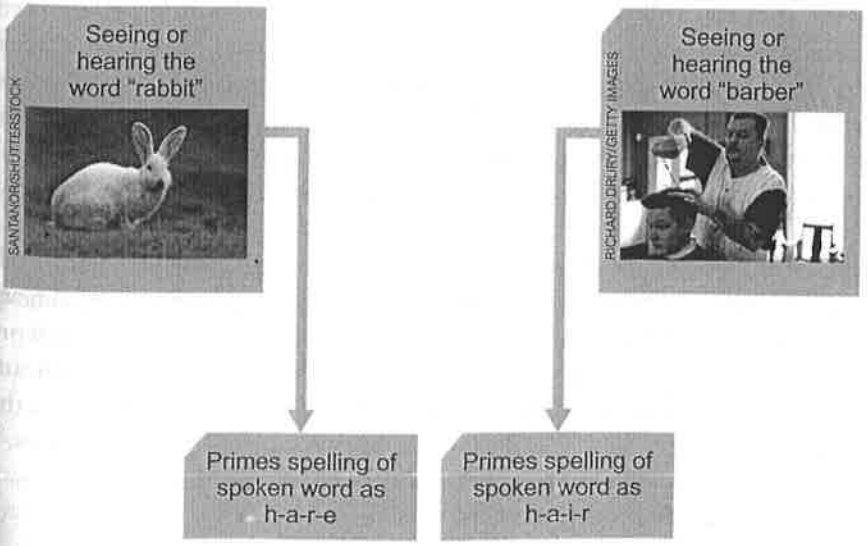


FIGURE 23.12
A Hare-Raising Experience
If you show people a picture, you can activate certain associations in their memory pathways—a process known as priming. When you later ask them to spell a word that can be spelled in two ways (*hare* or *hair*), their response may reflect the content of the picture. Thus, a picture of a rabbit is likely to activate the spelling h-a-r-e. A picture of a barber at work is likely to activate the spelling h-a-i-r. (Adapted from Bower, 1986.)

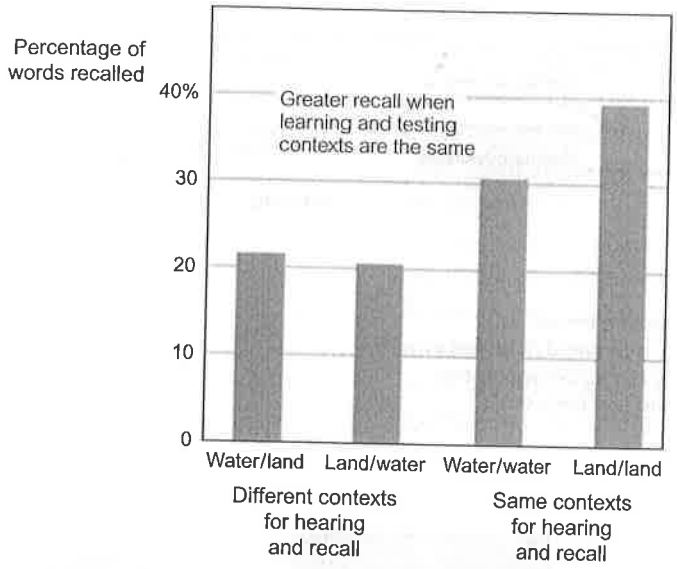


FIGURE 23.13
Context and Memory
As this rather odd experiment demonstrated, retrieval is best when it occurs in the same environment where encoding took place. In this case, the context was either under 10 feet of water (while scuba diving) or sitting on the shore. (Adapted from Godden & Baddeley, 1975.)

becomes relatively easy to integrate new information. This interrelated web of association allows for easy priming of memory and thus more effective retrieval.

Now that you know what the two types of retrieval are, let's turn to two factors that influence our ability to retrieve: context and state dependency.

Context

Context is the environment in which you encode or retrieve information. When you are in an environment similar to the one in which you encoded the information, you may experience the **context effect**—an enhanced ability to retrieve information more effectively. This happened when my wife and I visited a little town in Oregon where her family vacationed many years before. When we arrived, her memories began flooding back, and she was able to direct me to several landmarks around town. Returning to the context where she had encoded the memories primed the retrieval of those memories years later. One rather quirky experiment carried this idea even further. The researchers divided scuba divers into groups and read each group a list of words. One group heard the list onshore; the other group heard the list underwater (see **Figure 23.13**). Later, those who heard the words onshore recalled more of the words when they were onshore, and those who heard the list underwater recalled the words better underwater.[40] Any environment provides countless cues that can later function to prime the retrieval of memories.

context effect The enhanced ability to retrieve information when you are in an environment similar to the one in which you encoded the information.

State Dependency

Our ability to retrieve memories also depends on the physical or emotional state we were in at the time we encoded an event. **State-dependent memory** is the enhanced ability to retrieve information when you are in the same physical and emotional state as you were when you encoded the information. Strangely, if you were tired when encoding, retrieval will also be better when you are tired. Note, however, that you will neither encode nor retrieve as well when you are tired as you would if you were not tired. Do you drink caffeinated drinks, like coffee or Coke, when you study? Chances are you retrieve better under the influence of caffeine. This even extends to drugs that normally disrupt learning, like alcohol.[41] Despite its overall negative effects, if you were under the influence of alcohol when encoding, you would retrieve somewhat better (although not well!) with alcohol in your system.

state-dependent memory The enhanced ability to retrieve information when you are in the same physical and emotional state you were in when you encoded the information.

The retrieval of memories also depends on your mood. If you're happy when you encode, you'll retrieve better when you're happy. But if you've been somewhat depressed as you worked your way through a particular unit in a class, you'll probably test better when depressed. Odd, isn't it? Perhaps even more significant is the way our moods bias our memories. If you're in a good mood when you think back to first grade, the mood is likely to prime positive first-grade memories, but if you're depressed when you try to remember, your mood is likely to function as a retrieval cue for negative memories.[42]

Lose your memories, and you've lost your sense of self. Without the past, both joy and sadness would be fleeting, and our world would be shallow indeed. We would have no way to connect events, and we would be unable to learn anything. Our waking hours are a constant progression of encoding important information into memory, storing countless pieces of information on both a short-term and a long-term basis, and retrieving needed information from long-term storage. If you remember nothing else about this topic, remember the remarkable, amazing role memory plays in our daily lives.

MAKE IT STICK!

1. How can context and state contribute to the retrieval of memories?
2. True or False: A multiple-choice test is based on recall retrieval.
3. Memories can be triggered or _____ by other memories or stimuli that lead you down the neural pathway to a memory.

Module 23 Summary and Assessment

Information Processing

23-1 What are the factors that allow us to effectively encode information into our memory system?

- Automatic processing is the unconscious process of encoding certain information without effort. Effortful processing is encoding that requires attention and conscious effort.
- The serial position effect is the tendency to recall the first and last items on a list more easily. Distributed rehearsal works better than massed rehearsal.
- Semantic encoding is the process of making material meaningful. Visual images are often automatically encoded and remembered well. Mnemonic devices are memory tricks like the method of loci and the peg-word system. Chunking and organizing information into a hierarchy are effective encoding techniques.

23-2 What distinguishes sensory, short-term/working, and long-term memories?

- Sensory memory is the brief, initial encoding of iconic (visual) and echoic (sound) information in the memory system. Short-term/working memory contains information you are consciously aware of before it is stored more permanently or forgotten. Long-term memory is the relatively permanent and limitless storehouse of the memory system. Memories are stored in the brain through long-term potentiation.
- Stress hormones tell your body that something significant is happening, triggering biological changes that enhance memories. Explicit memories—recall of facts and experiences—are processed through the hippocampus. Implicit memories—recall of skills and procedures—are processed through the cerebellum.

23-3 What factors influence what we can remember and what we forget?

- Identifying whether something matches information in our long-term memory (recognition) is easier than recalling information.
- The other major factor that influences what we remember is context: It is easier to remember information if we are in an environment similar to the environment the information was encoded in (context effect) or if we are in the same emotional and physical state we were in when we encoded the information (state-dependent memory).