5

Short-Term Memory and Working Memory

> "You have to begin to lose your memory, if only in bits and pieces, to realize that memory is what makes our lives. Life without memory is no life at all. . . . Our memory is our coherence, our reason, our feeling, even our action. Without it, we are nothing."
>
> —Luis Buñuel

To a large degree, our sense of who we are depends upon what we know, and what we know depends upon our ability to remember what we have learned. **Learning** is defined as the permanent change in behavior that results from experience. But this learned information must be stored within us in order to be retrieved later. This process of storage is **memory**: the mechanism that allows us to retain and retrieve information over time. Memory is an essential, underlying, cognitive process that supports learning and makes it possible for us to acquire new knowledge and remember new information as we encounter new situations. This chapter and the three that follow comprise a unit that describes the different memory mechanisms we all possess, and how what we know helps us to learn more and function effectively.

A major goal of this unit is to explain some of the subtleties and complexities lurking just below the surface of the memory processes that we generally take for granted. We begin by describing what has been called **short-term memory (STM)**, the memory that contains our moment-to-moment conscious thoughts and perceptions. Short-term memory is fleeting: Its contents endure only as long as we are paying attention to them. Psychologists have historically found it easy to do research on the nature and limits of STM because people have immediate experience of its presence. In contrast, we have less awareness of **working memory (WM):** the set of mechanisms that underlies STM and also communicates with long-term memory (LTM), the semipermanent memory store that endures for a lifetime and aids us in learning new information. LTM will be the focus of Chapters 6–8. In this chapter we will discuss STM and its structural support, WM.

CHAPTER OUTLINE

Short-Term Memory (STM)

Short-term memory reflects our conscious awareness. We rely on STM as we carry out everyday activities like remembering a phone number long enough to call it, remembering the play signaled by the third-base coach before taking a swing, or thinking about our next response in a conversation. In order to understand this memory system, we will consider its properties in terms of the same basic questions that were used in the previous chapter to understand sensory memory:

- What is the capacity of STM?
- How long does information last in STM?
- Why do we forget facts held in STM?

The Capacity of Short-Term Memory

As its name implies, our short-term memory allows us to retain information for a brief period of time. How much information can STM hold? Researchers have devised a number of precise procedures for determining STM capacity (see Focus on Methods). These procedures have yielded data showing that a typical adult's memory span is approximately 7 (between 5 and 9) unrelated items (Miller, 1956). STM capacity typically increases as people age until it reaches a maximum in young adulthood (Dempster, 1981; Huttenlocher & Burke, 1976) and starts to decline in old age (Kail & Salthouse, 1994).

FOCUS ON METHODS

Short-Term Memory Capacity

The typical way of measuring STM capacity, also called *memory span*, is to present a sequence of numbers, letters, or words aloud to a person at the rate of about 1 second per item. The research participant is instructed to repeat the sequence verbally, either in the order each item was presented or in a backward order (Bunting, Cowan, & Saults, 2006; Wilde & Strauss, 2002). The length of the sequence is continually increased until the person is correct only 50% of the time.

Another procedure is to average the number of items in the three longest sequences that the person gets 100% correct and call that the memory span. To make sure that the person being tested doesn't know how many items are in the list, and thereby develop a special memory strategy that artificially increases their memory span, a *running memory span* test is used in which the number of items on the list varies from list to list (Pollack, Johnson, & Knaff, 1959). The Table shows that STM capacity increases with age until, on average, people remember 7 items by age 18. Researchers have proposed three explanations for the expansion of STM capacity as we age. One explanation is related to neurological development, another concerns strategies that people employ as they get older, and the third is related to how the coding of information changes with age. These explanations are discussed later in the section on working memory.

Memory Span Across Age Level

Age (in years)	Memory Span (for digits)
2	2
4	3
6	4
8	5
10	6
12	6
18	7

Source: From Dempster, 1981

The basic findings concerning memory capacity go back to the research of Ebbinghaus (1885/1913), who sought to identify basic memory processes that are independent of people's past knowledge. To do this, Ebbinghaus used nonsense syllables (formed by inserting a vowel between two consonants) as the items to be remembered, and determined how many runs through a list of nonsense syllables it would take to recite a list perfectly. Try this yourself by doing the exercise in Demonstration 5.1.

DEMONSTRATION 5.1

Ebbinghaus Test of Memory Capacity

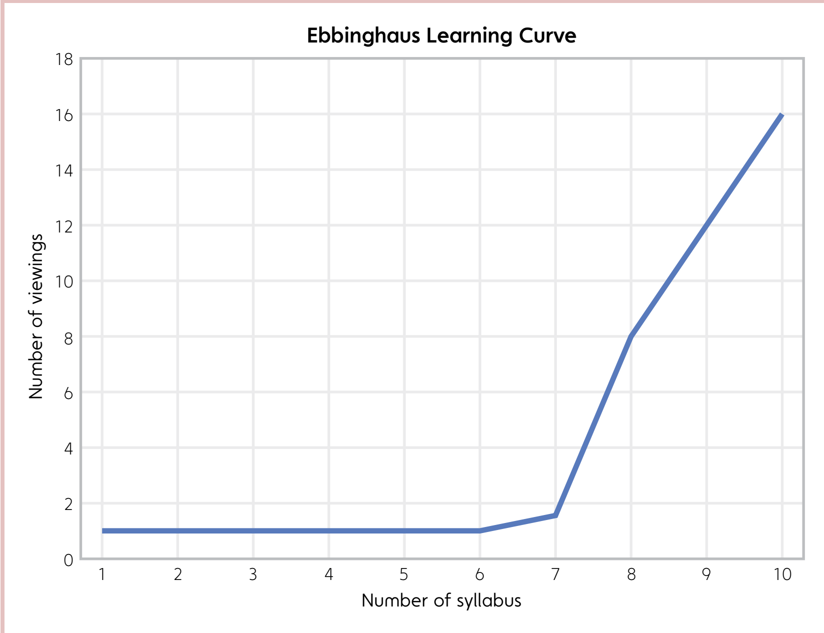
Over 100 years ago Ebbinghaus used what he called the "anticipation method" to study primary memory—what we now call short-term memory. To experience the kind of task used in this classic study, do the following: Take 10 pieces of paper and on each write one of the following: MEB, GEC, TER, BOL, CUV, FIK, DAL, HOK, PUV, and JUH. After turning the stack of papers upside down, lift each one, turn it over, read it for 2 seconds, and place it aside (face up, but don't look at it). After you read all 10 pages, turn the stack over again and try to guess the syllable written on each page. Check to see if you are correct, and then do the same for the next page until you've gone through the whole list. Keep doing this until you are able to anticipate the syllable on each page in the correct order. How many runs through the list did you require to get 100% correct? Now read on in the text to see how your efforts compared with Ebbinghaus's findings.

In Ebbinghaus's primary research, he used himself as the only participant to be sure that the data were reliable. He used lists of nonsense syllables that varied in length. If a list had 1 item, it only took one look at the item to be able to recall it perfectly. With lists of 7 items he required a single run through the list to recall the items with 100% accuracy. With a list of 10 items (just like the one you were given in the demonstration), it took 16 viewings of the list to remember the list correctly. How well did you do? The relationship between the length of the list and the number of viewings that a person needs in order to have a perfect memory for the list is shown in **FIGURE 5.1**. The important point is that Ebbinghaus discovered that there is a discontinuity—a jump in the curve—between the length of the list and the number of viewings needed to recall it perfectly. Notice that in Figure 5.1 this discontinuity occurs at about 7 items. The number 7 holds fast for lists of nonsense syllables, unrelated pictures, words, whatever you can think of as long as the individual items are unrelated. Cognitive researchers have tested memory for all of these items in their efforts to determine STM capacity.

Chunking and Short-Term Memory It is tempting to think of STM as a kind of empty bag with a limited holding capacity. However, cognitive research reveals that STM is not just a formless reservoir, it has a structure. For example, during an assessment of a person's memory span, if the pacing of the items is broken up with pauses between every third and fourth item, the person's memory span will be greater than if no pauses are inserted (McLean & Gregg, 1967; Ryan, 1969; Wickelgren, 1964). It is no accident that when radio and television advertisers

FIGURE 5.1 The Ebbinghaus Learning Curve The graph shows how many times Ebbinghaus needed to look at lists of different lengths before he could recall them perfectly. The sharp elbow in the curve at 7 items reflects the maximum he could store in STM. This discontinuity holds for any list as long as the individual items are unrelated.

Source: Based on Ebbinghaus, 1885/1913, Figure 6



recite a phone number they pause between every three or four digits. Otherwise, the listener will have difficulty retaining the sequence. In a sense, the spoken digits between the pauses have become a single unit or **chunk** of information.

The idea that information in STM can be grouped, which increases the capacity of memory, was proposed by Miller (1956) in "The Magical Number Seven Plus or Minus Two: Some Limits on Our Capacity for Processing Information." Miller concluded that the capacity of STM was really between 5 and 9 meaningful items or chunks of information for the typical adult. In this case, the word "meaningful" refers to whether the person is able to find a way of relating the items to what he or she already knows. This process is called **chunking.** Take the following series of 12 numbers, for example. Assume that someone presents this list to you at a rate of 1 number per second and that you have been asked to memorize the list:

1 4 9 2 9 0 2 1 0 7 1 4.

If these numbers were presented to you verbally (you could hear but not see them), and you didn't pay much attention to the relationship among the numbers, you might be able to recall about 7 of them in the correct order. On the other hand, if the numbers activated information stored in your long-term memory, then you would notice 1492 (Columbus's discovery of America), 90210 (the title of a TV show), and 714 (the area code for Orange County California—the O.C. and Surf City). The person who noticed these three chunks of information would most likely be able to recall the entire 12 digits and would be judged to have an enormous memory span. The effect is striking even with a single word. Take for example, "abracadabra." To someone unfamiliar with magical words in fairy tales ("hocus pocus" or "wingardium leviosa"), this would simply be a series of 11 letters or five syllables. Such a person would have difficulty recalling this string of letters perfectly. However, because of the chunking process, someone familiar with this word will see it as a single entity and will be able to recall it with little effort. The important message here is that what we have learned and stored in LTM can play a useful role in retaining information in STM.

The Importance of Prior Knowledge To be a chunk, something needs to fit together readily as a pattern distinct from the things around it (e.g., Gobet et al., 2001). For words or pictures to be a chunk, they need to be familiar to the person (Miller, 1956) and available in long-term memory. This illustrates that STM overlaps with—and relies upon—LTM to function efficiently. The depth and breadth of our knowledge in any given subject can influence our memory for new information related to that subject. This is one reason why someone may exhibit phenomenal memory ability in one class at school, but may perform at an ordinary level in another. The difference is due to what the person already knows.

Since prior knowledge affects everyone's ability to chunk and therefore retain information in STM, our estimates of a child's memory span may greatly depend on how familiar the child is with the testing materials being used (e.g., Huttenlocher & Burke, 1976; Santos & Bueno, 2003). For example, if a child is not familiar with numbers at the age of 4, but knows common one-syllable words, the child may show a memory span of 2 for numbers, but a span of 3 for words. Memory span tests, therefore, should be tailored to the person. There are no *pure* tests of memory that work for everyone: What is meaningful for one person may be meaningless for another.

This fact is illustrated by a study conducted by Chi (1978), who tested 10-year-old advanced chess players and found, not surprisingly, that their memory span using numbers was inferior to an adult group of inexperienced chess players. Chi then asked the children and the adults to look at a chessboard for 20 seconds and try to reconstruct the configuration of pieces that were on the board (14 pieces). On this task, the children performed better than novice chess-playing adults. This shows that for both children and adults, memory span is influenced by preexisting knowledge (Bjorklund, 1987): long-term memory.

Duration, Forgetting, and Short-Term Memory

We know that information is kept in short-term memory for a short period of time (hence its name). But, how short is *short*, and why are items lost from STM? The standard method of calculating the duration of information in STM is called the Brown–Peterson task after the researchers who separately developed the procedure (Brown, 1958; Peterson & Peterson, 1959). Try the task yourself by following the instructions in Demonstration 5.2.

DEMONSTRATION 5.2

The Brown–Peterson Task

To perform this task, you will need paper and a timer (a buzzer, a watch with a sweep-second hand, or a stopwatch will work). If you have a friend to assist you with this demonstration it may help. For each of the three cases listed below, set your timer for the seconds listed to the right of the letter/number combination. Have your friend read aloud the triplet of letters and then the three-digit number next to it. Immediately after you hear the number, count backward by threes from the three-digit number (e.g., if the number is 780, you would recite 777, 774, 771, etc.). Stop counting when the timer goes off and try to write down the triplet of letters. Try this procedure three times using Items 1-3 below, each of which calls for a different time duration. Ready?

Letter/No. Combination	Duration	Recalled Letters
1. VZN 823	0 seconds	
2. LQB 282	10 seconds	
3. XHR 941	20 seconds	

How did you perform? If you are like the students in the original study, the number of letters in each triplet that you are able to recall declined the longer you were asked to hold the letters in memory by counting backward by threes.

Two important findings related to the duration of STM have come out of research using the Brown–Peterson task: First, the number of items that can be kept in STM rapidly decays with the passage of time. You can see this in **FIGURE 5.2**, which shows that nearly perfect recall occurs with a 0-second delay and only about 10–20% recall occurs with an 18-second delay. For a realistic

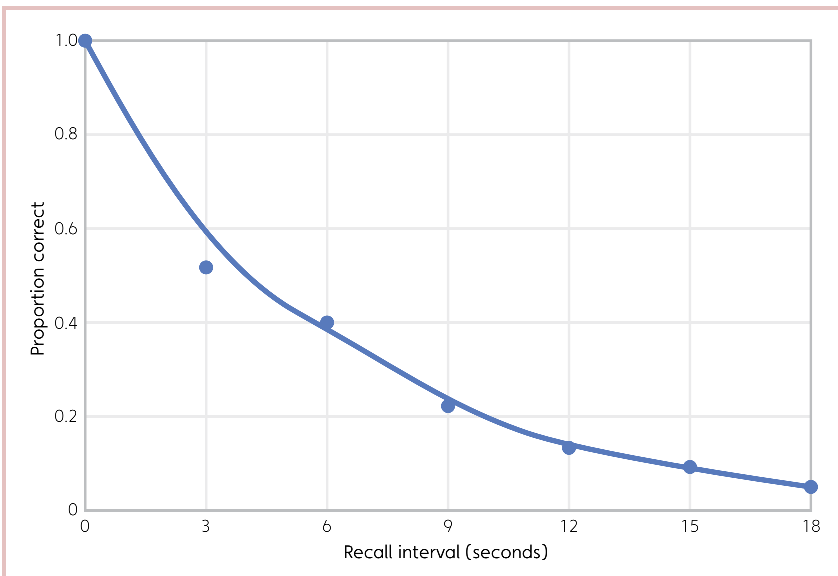


FIGURE 5.2 The Brown–Peterson Task The number of items that can be kept in STM declines rapidly without rehearsal. The graph shows that items in STM are perfectly recalled when there is only a 0-second delay. But recall declines to 10–20% accuracy when there is a delay of 18 seconds.

Source: From Peterson and Peterson, 1959 example of this, imagine you are told a street address and then are immediately distracted by a question. In this situation, your ability to recall the street address would be significantly impaired within 18 seconds. To use a common metaphor in cognitive psychology, it's as if the items in STM decay with time. The duration of unrehearsed information in STM is approximately 18 seconds. In the demonstration, did the number of letters you were able to remember decline as the time to count backward increased?

The second finding from this research is that the duration of items in STM is related to the number of chunks that are present. For example, three unrelated letters, such as C-H-J (equivalent to three chunks), show the same loss of information over time as three words, such as CAT-HAT-JUG (Murdock, 1961). In contrast, a single word (or a single letter) in STM shows virtually no loss. The number of chunks influences our ability to keep information in STM. It appears that the more items or chunks in STM, the more opportunities there will be for them to become confused with one another. This confusion is called *interference* and is an important contributor to our inability to recall items in our STM.

Interference Interference may be broken into two broad categories: retroactive and proactive. **Retroactive interference** occurs when what you know now makes it difficult to recall something that occurred previously. (Trying to remember your current phone number may make it difficult to recall one you had many years ago.) In contrast, when something that you have already learned interferes with your ability to recall more recent events, it is called **proactive interference**, which is a source of interference that plagues performance in memory tasks and in everyday life. (If you take a class in Spanish and then take one in French, Spanish words will typically intrude upon your consciousness as you try to speak French.) Proactive interference can be embarrassing as well as frustrating, such as when you call a new romantic partner by a former partner's name. Proactive interference influences memory performance on the Brown–Peterson task discussed previously. The first time students participate in the task, they show very little loss of information (Keppel & Underwood, 1962), but after many trials, the curve shown in Figure 5.2 emerges because the task becomes more difficult with each new trial. Letters from earlier trials start to be mistaken for letters appearing in more recent trials. Fortunately for people who are trying to memorize facts for school or work, proactive interference does not last forever. It can be stopped if the information people are being asked to remember is changed to a different type of information. For example, there seems to be little proactive interference when participants switch from having to remember letters to remembering numbers (e.g., Wickens, Born, & Allen, 1963), or switch to remembering words from a different subject area (e.g., Loess and Waugh, 1967; Wickens, 1970). This explains why taking a break during study sessions can be so effective. Doing something else for a while reduces proactive interference, thereby increasing recall of what you are trying to learn (Loess & Waugh, 1967).

Something has caused the members of this jury in a federal court to pay close attention. Paying attention, or rehearsal, is one way we retain information in STM.

Rehearsal Although pieces of information in STM last only about 18 seconds when we are not attending to them, those same pieces of information can endure in STM as long as we pay them attention. The act of paying attention is called **rehearsal**. Focusing our energies on the form and meaning of the thing we are trying to retain—rehearsing it—allows us to keep it fresh in STM. There are two kinds of rehearsal: maintenance rehearsal and elaborative rehearsal. **Maintenance rehearsal** is typically accomplished by saying something repeatedly in order to keep it in mind. This sort of rote rehearsal maintains the items in STM, but does not guarantee your permanent ability to recall the items freely after you stop rehearsing them (Glenberg, Smith, & Green, 1977). However, such rote memorizing can help you recognize the items later (Green, 1987). Maintenance rehearsal is a good strategy if you want to keep a phone number in memory long enough to call it, or if you want to be able to pick a number out of a list later on, but it is not a good way to be able to call the same number tomorrow (Craik & Lockhart, 1972). **Elaborative rehearsal** is accomplished by thinking about the meaningful relationship among the items to be learned and focusing on how they connect to other things that you know (Craik, 2002). This type of rehearsal strategy often results in enhanced long-term recall and recognition of things to be remembered (e.g., Benjamin & Bjork, 2000; Franklin et al., 2008; Mandler, 1980).

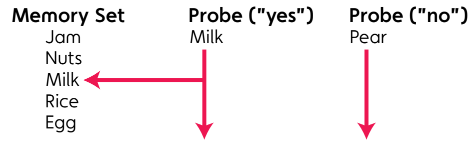
Why would either type of rehearsal be effective in helping us to retain information in STM? Whenever we rehearse an item, we are paying attention to it. One might say that each time we attend to something, whether it is an idea or a flower in our front yard, we enhance the energy of that item, sometimes called its *activation* (J. R. Anderson, Bothell, Lebiere, & Matessa, 1998). If we stop paying attention to something, its activation level decays and it becomes more difficult to recall. Keeping things activated in memory has the effect of keeping them available for recall. Elaborative rehearsal is a more effective means of retaining and recognizing items over a long period of time. That is because having many connections associated with something to be remembered increases its level of activation so that its retrieval is more likely to be triggered by a simple cue or reminder.

Retrieving from Short-Term Memory

Having examined the capacity and duration of STM, we turn to how information is retrieved from STM. Suppose you are told to go to a store and buy six items (e.g., apples, bread, soup, peanut butter, cereal, milk) and within a few seconds someone asks you whether milk is on the list. How do you search your memory to decide whether an item is stored in STM? To determine the processes that we use to retrieve facts from STM, Sternberg (1966, 2004) developed a task that bears his name: the Sternberg task. The structure of the task is illustrated in **FIGURE 5.3**. In it, a participant is given a set of up to seven items, which are presented rapidly, one at a time, over the course of a few seconds. Soon after, a memory test item, called a *probe* (e.g., milk), is presented and the participant must determine whether or not the probe is part of the memory set.

Many theories of how people scan their STM have been rigorously tested. The theory researchers now believe to be correct requires some uncommon sense to understand, and illustrates that our intuitions about how our minds work are not always correct. Researchers refer to this theory as **serial exhaustive search.** This theory proposes that we search every item in our STM in response to a question and do not stop searching even when we find the item in memory. Rather, we search our STM in its entirety—exhaustively. **FIGURE 5.4** shows what the data confirming the serial exhaustive search theory look like. The graph contains a positive line and a negative line. The positive line reflects the time it takes people to correctly say, "Yes, the probe is in my STM." The negative line reflects the time to correctly say, "No, the item is not in my STM" when it has not been found. The exhaustive search theory assumes it will take a person just as long to scan memory for a positive probe as for a negative probe because the entire list must be searched in both cases. In addition, the lines illustrate that as the size of the memory set increases (goes up on the right), so does the time needed to answer the question about what is in STM because the more items to be searched, the longer it takes.

The graph contains information that reveals two important aspects of STM search. First, the lines have a slope: the angle of the line compared with the horizontal. For every new item to be searched in STM, the line goes up 30–40 milliseconds on the vertical axis. Second, the lines intersect the vertical axis when the



Note: In typical studies, the list of items to be scanned contains numbers or letters.

FIGURE 5.3 Sternberg Task Diagram To determine how people retrieve items from STM, participants in the Sternberg task are given a set of up to 7 items to store in STM. The items are presented rapidly, one at a time, over the course of a few seconds. Soon after, a memory test item (called a probe) is presented. Participants must decide whether or not the probe is contained within their STM.

Based on Sternberg, 1966

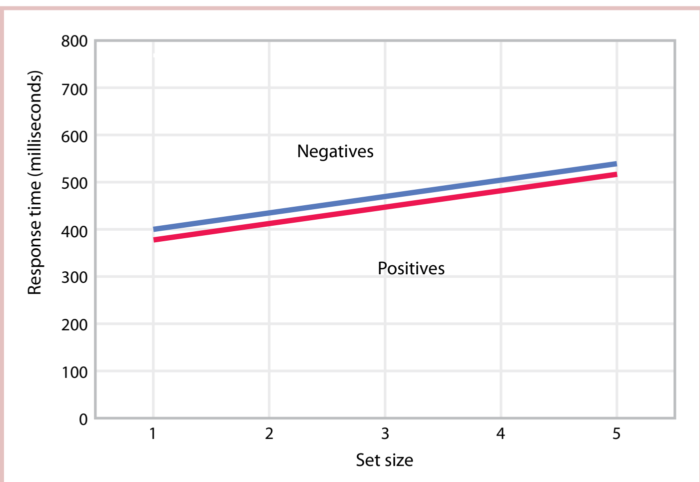


FIGURE 5.4 Memory Scanning The data in this graph confirm the serial exhaustive search theory. The positive (red) line reflects the time it takes a participant to correctly say, "Yes, the probe is in my STM." The negative (blue) line reflects the time to correctly say, "No, the probe is not in my STM" when it has not been found. The time to scan STM increases with the number of items in memory (40 ms/item), and a participant will take as long to scan for a positive probe as for a negative probe because the entire list must be searched in both cases.

set size is empty. The time at this point of interception is about 400 milliseconds. This point of interception represents the time needed to make the overall decision, including the time to press the button and the time to read the question, irrespective of what is in STM.

The serial exhaustive search theory shows that sometimes the correct hypothesis runs counter to our intuitions (e.g., Roberts, & Sternberg, 1993): Who would have thought that even after you find a probe item in STM, you would continue the search? Serial exhaustive search makes sense, however, if you imagine that you are in a ski race and want to see if your best friend is watching as you barrel down the hill in a slalom. You could proceed in two ways. One way would be to follow a self-terminating search procedure: You could ski slowly down the hill, examining each spectator until you find your friend and then, having terminated your search, you could speed up to the bottom—undoubtedly losing the race. In contrast, following an exhaustive search procedure, you could charge down the hill as quickly as possible while still searching the spectators for your friend. It might take you a few seconds after you spot him or her to be aware that your friend was actually watching you race. By that time, you would have reached the bottom of the course. The more spectators you scan, the more efficient is the serial exhaustive search. The serial exhaustive explanation has been critically tested in many studies (e.g., J. A. Anderson, 1973; Theios, 1973; Townsend, 1971, 1990) and is still the dominant explanation of how we scan our STM.

These findings with healthy populations allow us to gauge the memory processes of clinical populations, such as people with Parkinson's or Alzheimer's dementia (e.g., Ferraro & Balota, 1999). **FIGURE 5.5** shows the different slopes

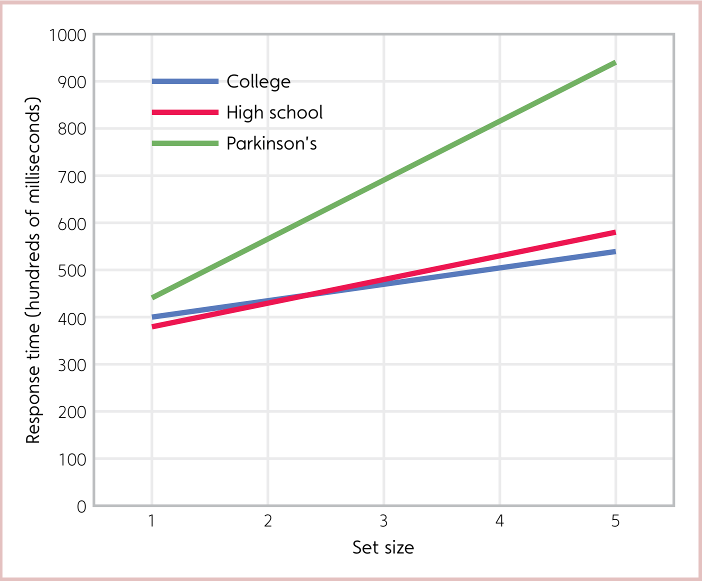


FIGURE 5.5 Memory Scanning Data for Different Groups In this graph, the slope of the lines reflects the time to compare items in memory. Individuals with Parkinson's disease require considerably more time per item to compare two things in memory than do healthy high school and college students. All three groups are equivalent in their overall time to read and respond, as reflected by where the lines intercept the vertical axis. Memory-scanning procedures help researchers identify the sources of difficulty in memory retrieval as well as to assess the effectiveness of different treatments.

Source: After Hunt, 1978

and intercepts for three groups using this memory search task (Hunt, 1978). You can see from this graph that although individuals with Parkinson's respond as rapidly as typical high school students, they require considerably more time per item to compare two things in memory. The use of this kind of standard task enables researchers to identify sources of difficulties in memory retrieval as well as to assess the effectiveness of different treatments. For example, if a drug improves memory scanning, it should affect the slope of the line. However, if it merely makes someone faster in responding, but not better at memory search, it should affect only the intercept.

SECTION SUMMARY

Short-Term Memory (STM)

Short-term memory is the memory system that contains our moment-to moment conscious thoughts and perceptions: from admiring the beauty of a sunset to remembering where we put our keys. STM is fleeting: Its contents endure only as long as we are paying attention to them. The capacity of STM increases with a person's age until it reaches a maximum of 5 to 9 meaningful items, called chunks. These chunks reflect the continuous connection between short-term and long-term memory. As long as we are able to rehearse, or pay attention to the information in STM, it can reside there indefinitely. However, without rehearsal, the information is lost from STM in about 18 seconds. Interference among the items is the primary contributor to the loss of items from STM. There are two types of interference: retroactive interference (new information preventing the retrieval of old information) and proactive interference (old information preventing the recall of new information). We can keep information in our STM by using two major kinds of rehearsal methods: maintenance and elaborative rehearsal. Both methods keep information active in STM, but only elaborative rehearsal promotes recall even when we stop rehearsing.

To answer a question about the contents of their STM, people perform a serial exhaustive search. They check each item in STM against the item mentioned in the question. Unlike reading a list of items on a piece of paper and stopping when we have found the target, our memories are scanned completely. The more items in STM, the longer it takes to decide whether or not a questioned item is present in memory. Different populations of people can be compared based on how much time it takes them to decide whether an individual item is in memory and how much time it takes them to respond overall. This information can be used to gauge the effectiveness of therapies designed to improve STM.

The Serial Position Effect

When we try to remember a list of items in any order, the accuracy of our retrieval of the items shows an interesting relationship to the original list: Items at the beginning and end of the original list are much more likely to be remembered than items in the middle of the list. This phenomenon is called the **serial position effect** because the probability of recalling an item tends to be related to its position among other items on a list. This is illustrated in **FIGURE 5.6** for lists that are presented aloud and in writing. The serial position effect is found in studies testing memory for lists of numbers, facts, states, colors, pictures, and even ideas within paragraphs or the final scores of soccer games over an entire season (e.g., Manning, 1980; Phillips & Christie, 1977; M. J. Watkins & O. C. Watkins, 1974). Each memory curve in **FIGURE 5.7** shows that the early part of the list is remembered better than the middle part of the list. This is called the **primacy effect.** Similarly, the last items on the list (those items most recently encountered) are also remembered better than the middle items. This is called the **recency effect** (Phillips & Christie, 1977). Notice that the serial position effect holds for all of the list sizes and conditions in the graph in Figure 5.7.

The serial position effect is another example of the interaction between short-term memory and long-term memory. To experience this first hand, try the task in Demonstration 5.3.

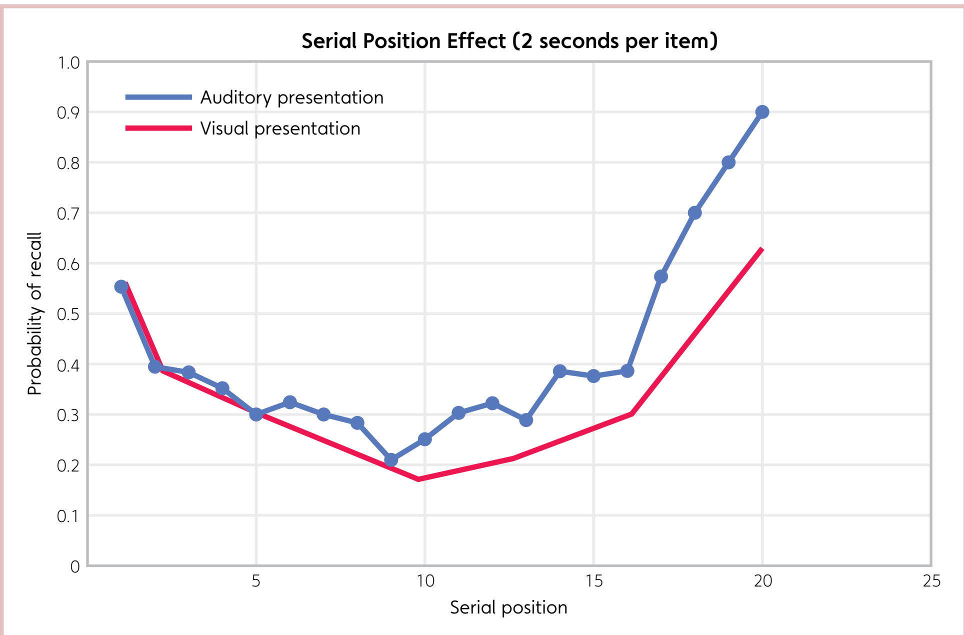


FIGURE 5.6 Serial Position Effect The serial position effect is found in studies testing memory for lists of numbers, facts, states, colors, pictures, and even ideas within paragraphs or the final scores of soccer games over an entire season. The ability to recall items from a list reflects where in the list the items come from and whether they are presented in a visual mode or an auditory mode.

Source: After Beaman and Morton, 2000

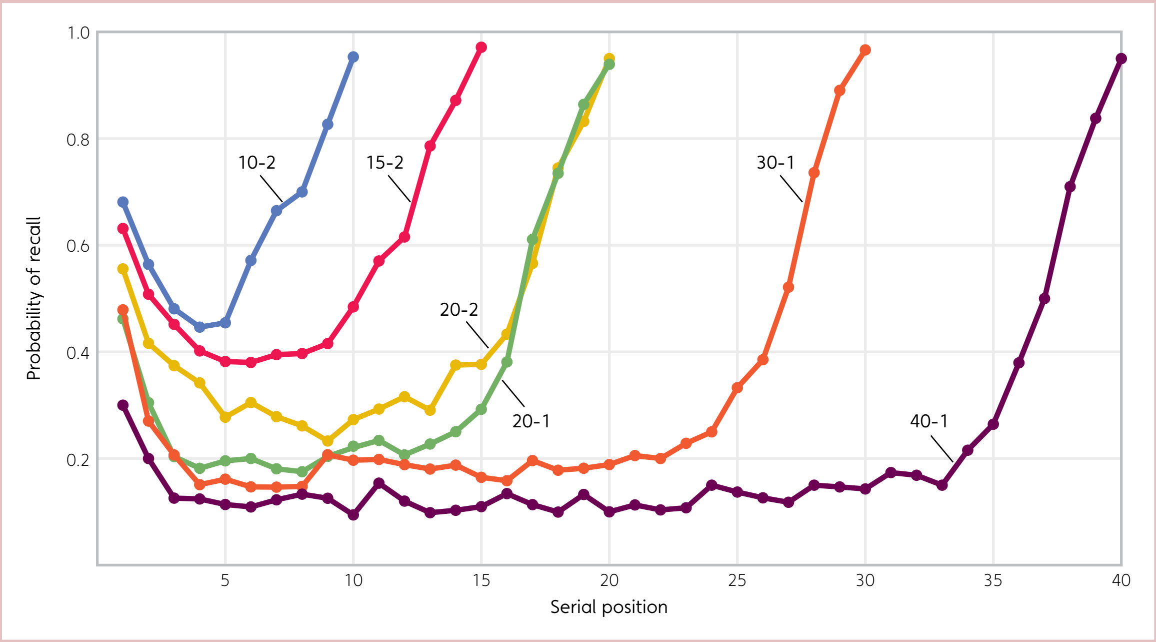


FIGURE 5.7 Serial Position Curves for Lists of Different Length The graph shows a serial position effect for all list lengths and presentation rates. The first number attached to each curve indicates the length of the list (e.g., 10, 20, 30, or 40 items). The second number tells how many seconds each word was presented (1 or 2 seconds).

Source: From Murdock, 1962

DEMONSTRATION 5.3

The Serial Position Effect

Memorize the following list of nine words in the correct order. You will need a clock with a sweep-second hand and a piece of paper to cover the words on the list. You may use a maximum of 4 seconds to memorize each word. Read the first word on the list with the rest covered, try to memorize it for 4 seconds, and then go on to the next word. As you move on to a new item, continue to rehearse the preceding items. Remember you have only 4 seconds. Every time you rehearse an item, make a mark next to the word to keep track of the amount of rehearsal each word receives. Here is the list:

BLINK	APPLE
CLEAR	DREAM
PLANT	FIELD
ALLOW	GRAIN
TROOP	

When the time is up, try to recall the entire list on a separate piece of paper. Students typically have the most marks at the beginning of the list. Next in order are the last two words on the list (rehearsed as the person prepares to write down the list). The fewest marks are typically next to the middle of the list.

The demonstration illustrates that the primacy portion of the curve (the first items to be committed to memory) generally reflects more rehearsal and attention because there is nothing before them that competes for a person's attention. This helps make these early items accessible to STM and LTM. Fewer rehearsals of items are possible as the list increases in length (Atkinson & Shiffrin, 1969; Tan & Ward, 2000). As a result, more attention is given to the early items than to the later ones. In contrast, the information at the end of the list, the recency portion, consists of words or other items that are newly placed in STM, which makes them immediately available, but only temporarily. Students typically recall these items immediately (e.g., Beamon & Morton, 2000).

The separation between STM and LTM has been tested in many ways. These tests show that some learning conditions affect the first part of the serial position effect but not the last part, while other conditions can affect the last part of the serial position effect but not the first part. For example, if students are forced to wait 30 seconds before trying to recall a list that they have just committed to memory, the last few items on the list—those stored in STM—will not be easily recalled because the delay is over 18 seconds. This phenomenon is called **negative recency** (Craik, 1970). Such delays don't affect recall for the information from the first part of the list, however, because those items are better rehearsed and are more likely to be encoded into LTM. Negative recency is not limited to recalling arbitrary lists of words: It has been shown to hold true for recalling commercials during a TV show (Terry, 2005). After a delay, observers have difficulty recalling the last few brand names touted by the most recent commercials.

Alternately, if people find it difficult to rehearse the first few items on a list, the primacy effect—memory for the early part of the list—can be eliminated. For example, researchers presented lists of words at fast rates (two words every second) and at slow rates (one word every 2 seconds). They found that the faster the rate of presentation, the poorer the recall of the words at the beginning of the list, although speed of presentation had no effect on memory for the last few items on the list (e.g., Murdock, 1962). This "speed effect" can be seen if you glance back at Figure 5.7 and compare the curves for 20 items (1 second) and 20 items (2 seconds). The ability to rehearse the first few items is critical to the serial position curve.

Implications for Memory

The serial position effect not only reflects rehearsal conditions (Bjork & Witten, 1974; Van Overschelde, 2002), it also reflects whether the items to be remembered are presented visually or auditorily. In one study, participants either read digits silently to themselves, or listened to the digits as they were read aloud. The results can be seen in Figure 5.6, which shows two serial position curves: one for visual information presented to students and one for auditory information. You can see from the figure that students had more difficulty recalling the last few items of a list when they were visually presented (read silently to themselves) than when they were auditorily presented (Beaman & Morton, 2000). This is called the **modality effect** (Crowder & Morton, 1969; O. C. Watkins &

M. J. Watkins, 1980) because there is a different recall pattern depending on the stimulus modality (visual or auditory) being used. This effect shows how important auditory rehearsal is to STM.

Perhaps you have noticed that immediately after someone speaks to you, the words "disappear" and you must rely on your STM to understand fully what was just said. Because of this, humans may have developed sound-based rehearsal to keep information available for processing. In contrast, our cognitive system does not always have to compensate for the loss of visual information because visual events are not usually as fleeting as sound—even moving objects can be kept in view for some time period.

Getting Around the Serial Position Effect

One way to circumvent the power of the serial position effect is to make the information distinctive, and therefore more memorable. For example, if you are studying with a friend and want to help him remember a list of vocabulary words, you can say his name periodically during the session (e.g., "good, Eric"). This will redirect your friend's attention to the new information and create the equivalent of a new list. Or, if you are trying to remember portions of a text that you have highlighted, keep changing the color of the pen you are using; this breaks up the "list" of facts and makes the first few items in the new color more memorable than they would be otherwise.

Another way around the serial position effect is to find a way to connect the information you are trying to remember. The U-shaped curve associated with the serial position effect is typical for items that are unrelated to each other, but not for lists of things that are related. Suppose you are trying to remember a list of items to buy at the grocery store. The serial position effect predicts that you are likely to forget the items in the middle of the list within a minute. However, if you form a visual image of each item and create a combined picture of the first item with the second and the second with the third, and so forth, then when you get to the store, recalling any item will help you recall the others on the list. As a result, you will probably not show a serial position effect (Bower, 1970). You can gain firsthand experience of this memory technique by trying Demonstration 5.4.

DEMONSTRATION 5.4

Ways Around the Serial Position Effect

Have you ever played the game "my grandfather owns a grocery store and he sells . . ."? This is a game where the first person states an object in the store, and each succeeding person repeats the already stated objects and then adds a new one to the end of the list. By creating a mental image of each object and picturing how it connects to the preceding object on the list, the serial position effect can be eliminated—a winning strategy for the game and for improving your memory of a list of items. You can experience this effect by applying the strategy to the following list of 15 words. To do so, form a visual image of each object and then connect each new image to the previous one. For example, say "apple" and imagine an apple, say "knife" and imagine a knife and an apple together, then say "plate" and put the apple–knife combination on the plate, and so on. The knife stabbed into the apple (maybe with a little blood) should do the trick (e.g., Kroll & Tu, 1988)! The key factor in this demonstration is not the use of imagery, but as we will see in Chapter 8, memory is enhanced when we create relationships among the items to be remembered. One further hint: The more bizarre the image you create, the better the recall.

APPLE	DOOR	BOWL
KNIFE	BELT	RAISINS
PLATE	BROOM	CEREAL
GLASS	TOWEL	CUP
MILK	SOAP	CRACKER

Another way around the serial position effect is simply to accept that people will forget the ideas in the middle of a message and remember only the information at the beginning and end of messages. Commercials for prescription medicines typically place the description of the drug's possible side effects in the middle of the commercial. This helps to make the negative information less memorable. The product's name is spoken at the beginning and end of the advertisement in order to make it more memorable.

SECTION SUMMARY

The Serial Position Effect

The items in the middle of a list are not as likely to be recalled as those at the beginning or end of a list and it doesn't matter whether the list is made up of TV advertisements, introductions to people at a party, or the main points in a textbook paragraph. This phenomenon, called the serial position effect, is represented visually as a U-shaped curve and reflects the dual operation of short-term memory and long-term memory. It is more distinctive for auditory presentations of information than for visually based presentations; this is called the modality effect. Each portion of the curve can be separately affected by the conditions in which the information is presented. If information is presented rapidly, it is difficult for a person to attend to each item so the primacy portion (first part of the curve) will show poor performance. If a delay occurs between the time the list is presented and the time it is recalled, the recency portion of the curve (last part of the curve) will show poor performance. Methods exist to help individuals avoid the serial position effect. These methods involve making each item in a list meaningful and mentally connecting list items to one another to form a memorable image.

Working Memory: The Structure Beneath Short-Term Memory

We have seen that STM behaves differently depending on whether the things to be remembered are presented visually or auditorily, rapidly or slowly, or whether the items activate information stored in long-term memory and where in a sequence of facts a critical item falls. Cognitive psychologists have developed a theory of the underlying mechanisms of STM not only to explain the properties of STM, but also to explain how STM helps us interact with the world and accomplish our goals. This emphasis on the active and structural aspects of STM began with the work of Miller, Galanter, and Pribram (1960). They called STM *working memory* to emphasize that it serves as our support system for doing cognitive work, such as reasoning, listening, or making decisions.

Great progress in this effort to replace the static model of STM with a more process-oriented model of working memory was made by Baddeley and Hitch (1974, 1976, 1977). They defined working memory as a limited capacity system that allows us to store and manipulate information temporarily so that we can perform everyday tasks. Their model of working memory is composed of the four subsystems shown in **FIGURE 5.8**: a phonological loop, a visuospatial sketchpad, an episodic buffer, and a central executive. The goal of the remainder of this section is to describe the cognitive functions performed by each of these WM components and to show how the properties of short-term memory can be explained by the mechanisms of working memory.

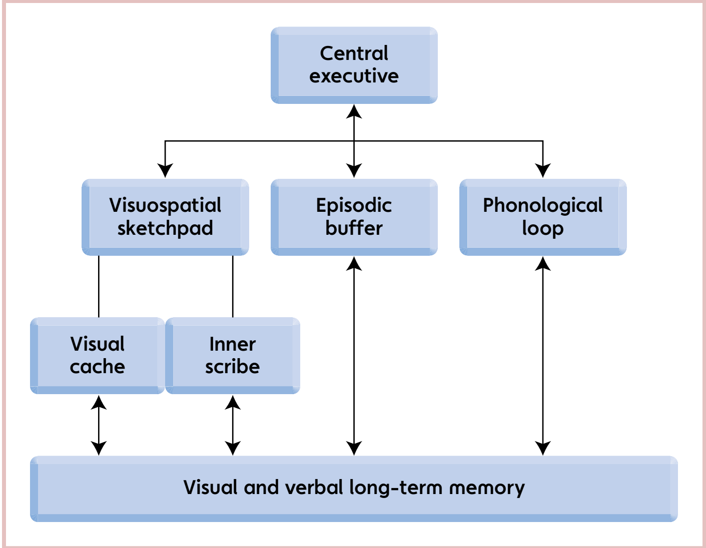


FIGURE 5.8 Working Memory System Baddeley and Hitch formulated a process-oriented model of working memory that is composed of four subsystems: a phonological loop, a visuospatial sketchpad, an episodic buffer, and a central executive.

Source: After Baddeley, 2000; Logie, 1995

The Phonological Loop

Sound is a primary means of conveying information. Even when we read silently, we often generate internal (subvocal) speech: a sound-based (phonological) representation of the visually presented words (e.g., Bookheimer, Zeffiro, Blaxton, Gaillard, & Theodore, 1995). Like the serial position effect, sound is one of the basic codes of STM. Not surprisingly, one of the subsystems in working memory is dedicated to the temporary storage of phonological information. This system is called the **phonological loop** and it contains two components: the **phonological store**, a reservoir in which an acoustic or phonological representation of the stimulus is stored; and the **articulatory control process** (like maintenance rehearsal), which automatically refreshes and maintains the elements in the phonological store. This control process refreshes the items in the phonological loop as if they were being rehearsed, though of course the process is subvocal, no sound is actually made.

Without the articulatory control process, the phonological store would be roughly equivalent to the original description of STM, because without the constant activation of the articulatory control process, items to be remembered would be lost over time. According to the WM model, the articulatory control process "refreshes" or automatically gives energy to each element in roughly a 2-second cycle. Any sounds (names, numbers, etc.) that can be repeated in 2 seconds can be maintained in WM

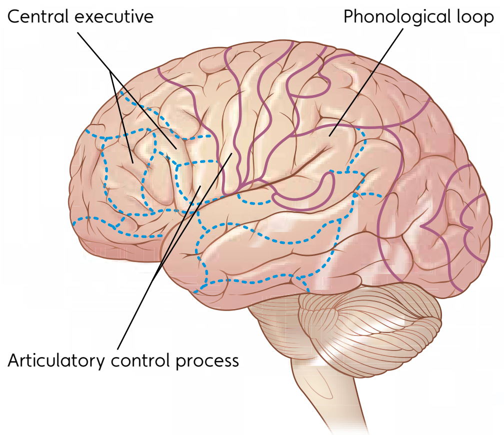


FIGURE 5.9 Working Memory and the Brain Specific areas of the brain are associated with the functions of the phonological loop and other subsystems of working memory.

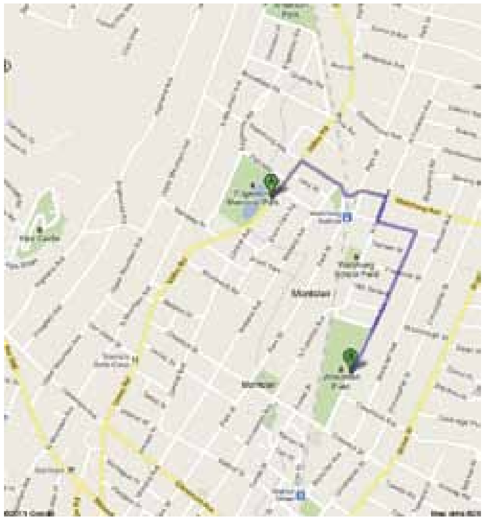
(Schweikert & Boruff, 1986). If a set of items requires more than 2 seconds to be repeated, some loss of information from memory will result because there is a trade-off in WM between the rate of loss and the rehearsal rate. When the items in the phonological loop are numerous or difficult to pronounce, the articulatory control process cannot keep up with refreshing all of the information in the phonological loop: The more information you have to process, the more information you will lose from working memory. This aspect of WM accounts for the fact that STM capacity has a limit because of the work required by the articulatory control process.

Neuropsychology of the Phonological Loop Specific areas of the brain are associated with the functions of the phonological loop and other subsystems of working memory. These are illustrated in **FIGURE 5.9**. The basic storage function of the phonological loop is associated with activity in the left parietal region (Nyberg & Cabeza, 2000; Shallice & Vallar, 1990; Warrington, 1971). It may also connect just below the left parietal region to the superior temporal lobe (Buchsbaum & D'Esposito, 2008), a central area for language processing, which will be discussed in Chapters 10 and 11. The refreshing of items within the phonological loop is associated with activity in the prefrontal cortex (Awh, Jonides, Smith, Schaumacher, Koeppe, & Katz, 1996; Paulescu, Frith, & Frackowiak, 1993). This part of the brain helps people understand human speech (see Chapter 9) and is connected to an area of the cortex, called the motor area, which gives commands to the muscles that allow us to speak. The fact that the areas of the brain related to WM are also important to speech supports the hypothesis that the articulatory control process is speech based. Moreover, the fact that the brain areas associated with storage of words are separate from the area that refreshes those words is evidence that the phonological loop is separate from the functioning of the articulatory control process.

The Visuospatial Sketchpad

Sometimes we are called upon to remember a picture, a dance sequence, or imagine a route through a new neighborhood. The cognitive processes that are mobilized to perform these actions rely on another component of working memory: the **visuospatial sketchpad** (see Figure 5.8). This WM component is responsible for storing visually presented information such as drawings or remembering kinesthetic (motor) movements such as dance steps. For example, when you read the word "cat" you see the letters and store them; however, if time permits you might also retrieve a visual image of your favorite cat and store that in the sketchpad along with the written letters. It works the other way as well: If you see a picture of a cat, you may implicitly verbalize something like the word "cat" (Glanzer & Clark, 1964; Smith & Larson, 1970). However, this requires the participation of the central executive, described later. The importance of the visuospatial sketchpad is evident when reading a textbook like this one that has words, figures, and illustrations that are related to one another. In this case, both the sketchpad and the phonological loop are working together to combine the information that is presented on the page as both words and pictures. The sketchpad maintains the visual representation of stimuli as well as their spatial position on the page (Hegarty & Just, 1989; Schacter, Wagner, & Buckner, 2000).

The visuospatial sketchpad contains two structures: the visual cache and the inner scribe (Logie, 1995, 2003; illustrated in Figure 5.8). The **visual cache** temporarily stores visual information that comes from perceptual experience and contains information about the form and color of what we perceive (Smyth & Pendleton, 1989). And, as if it were storing a picture, it also contains some spatial information about what is perceived. In contrast, the **inner scribe** performs at least two functions. First, it refreshes all of the stored information contained in the visuospatial sketchpad. Second, it briefly stores spatial relationships associated with bodily movement. The two together are involved in our common experience of visual imagery. The visual cache holds the images and the inner scribe can manipulate them. Both require the involvement of part of the central executive called the *visual buffer* to create our images (Logie, 1995; see also Bruyer & Scailquin, 1998; Pearson, 2001). Visual imagery will be an important topic in Chapter 8.



The cognitive processes that allow us to follow and remember a route on a map, like this one of Montclair, New Jersey, rely on the visuospatial sketchpad, a component of working memory.

In an experiment to determine whether the visuospatial sketchpad and the phonological loop are independent systems, university students were asked to memorize a miniature checkerboard with black and white squares: a perceptual task associated with the visuospatial sketchpad (Cocchini, Logie, Della Sala, MacPherson, & Baddeley, 2002). At the same time, the students either engaged in a motor task (also associated with the visuospatial sketchpad) or a verbal task (associated with the phonological loop). The motor task consisted of using a computer stylus to track a "ladybug" moving on a computer screen. The verbal task required the students to repeat back an ever-changing sequence of numbers (a typical digit-span procedure). Consistent with the concept of a visuospatial sketchpad, tracking the ladybug interfered with remembering the checkerboard (a spatial task). The digit-span task associated with the phonological loop, however, did not interfere with remembering the checkerboard. Thus, a spatial motor task interferes with perceptual information stored in the visuospatial sketchpad, but a phonological task does not. These findings support the theory that the visuospatial sketchpad and the phonological loop are separate, independent systems.

Neuropsychology of the Visuospatial Sketchpad The visuospatial sketchpad is represented in the brain in a manner similar to the phonological loop (see Figure 5.9) except that it is represented primarily on the right side of the brain (Courtney, Ungerleider, Keil, & Haxby, 1997; Smith et al, 1995). Cognitive neuroscience provides evidence in support of the theoretical distinction between the visual cache and the inner scribe. The functioning of these systems is associated with separate neurological areas (Levy & Goldman-Rakic, 2000; Sala, Rama, & Courtney, 2003).

Clinical cases also provide evidence for two subsystems. In one case, an individual with a lesion in the right prefrontal cortex had difficulty remembering spatial relationships among objects (information associated with the inner scribe), yet had no difficulty perceiving those same objects (information associated with the visual cache; Carlesimo, Perri, Turriziani, Tomaiuolo, & Caltagirone, 2001). The same effect can be seen in laboratory experiments. In one study researchers were able to "knock out" the ongoing electrical activity of the part of the brain associated with the functioning of the inner scribe using a procedure called *repetitive transcranial magnetic stimulation* (rTMS). By doing so, they were able to interfere with a volunteer's ability to remember the arrangements of dots (illustrated in **FIGURE 5.10**), but not a volunteer's memory for pictures. When the researchers

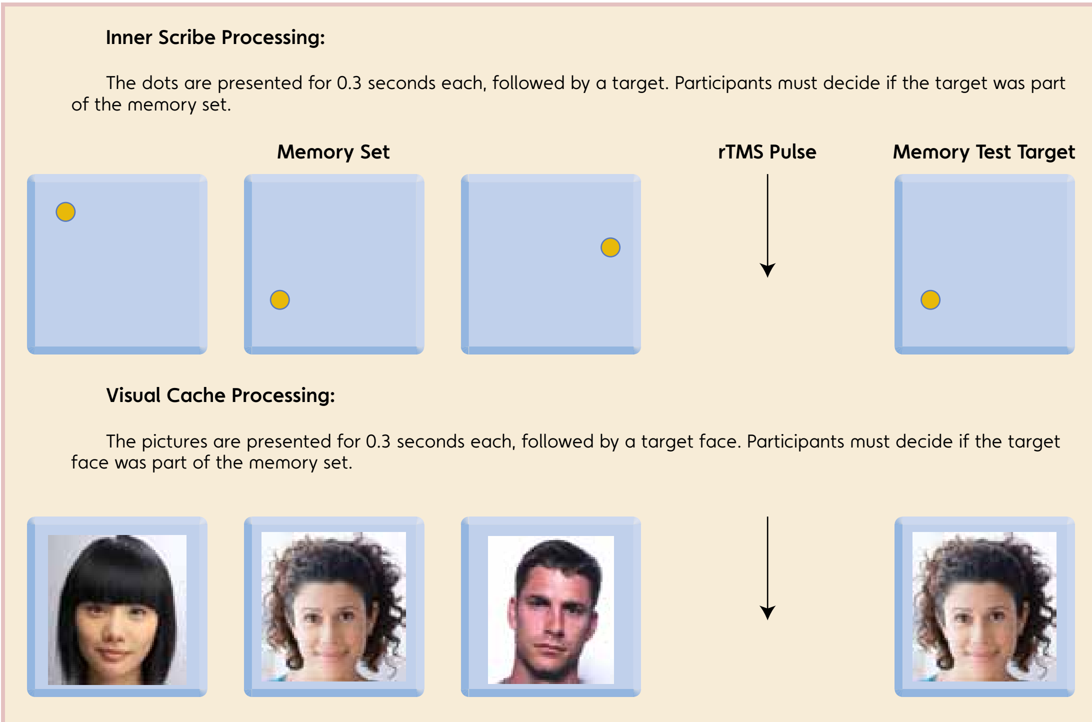


FIGURE 5.10 The Scribe and the Cache Are Separate Systems In this study, researchers were able to show that the inner scribe and the visual cache are separate systems. Volunteers performed two tasks: spatial memory for the pattern of dots (using the inner scribe) or memory for faces (using the visual cache). When performing these tasks, volunteers had targeted areas of their brain briefly knocked out by a pulse of repetitive transcranial magnetic stimulation (rTMS). When the rTMS pulse is sent to the area where the inner scribe functions (the dorsolateral medial prefrontal cortex) the dot pattern task is interrupted, but not the face recognition task. In contrast, when the rTMS pulse is sent to the visual cache area (ventrolateral prefrontal cortex), the face memory task is interrupted, but not the dot pattern memory task.

Source: Mottaghy, Gangitano, Sparing, Krause, and Pascual-Leone, 2002 subsequently used rTMS to knock out the brain area associated with the visual cache, they were able to interfere with memory for pictures, but not memory for the spatial arrangements of dots (Mottaghy, Gangitano, Sparing, Krause, & Pascual-Leone, 2002). This testing procedure demonstrates the independence of the two components of the visuospatial sketchpad.

The Episodic Buffer

When people are engaged in a conversation, they have to keep track of what has been said, the responses to what has been said, and their assumptions about what individual speakers intended by their remarks. It is as if every conversation is a ministory or "episode" with a beginning, middle, and end. To keep track of such episodes, researchers argue that WM contains an **episodic buffer**, which acts as an integrative system that places events occurring in the visuospatial sketchpad and the phonological loop into a coherent sequence along with memory for the goals that initiated those events (Baddeley, 2000, 2004). Because the episodic buffer keeps track of the sequence of sentences that are spoken to us, it is natural to suppose that some part of the phonological loop would be connected to episodic memory. This is just what neuroscientists have found: The lower portion of the parietal lobe (near where the phonological loop seems to function) acts as an interface between episodic memory and the executive systems. Of course we should not think that the episodic buffer is localized only to this area of the brain. Rather we must always suppose that this part of the brain operates in coordination with other regions of the brain to perform the basic WM functioning (e.g., Vilberg & Rugg, 2008).

To appreciate the usefulness of the episodic buffer, remember that STM research has found that the typical person can remember a list of about 5 to 9 unrelated words. Yet, when those words are organized as a normal sentence, memory span increases to 15 or 16 words (Baddeley, Vallar, & Wilson, 1987). This phenomenon is most evident in people whose attention is working well (Baddeley & Wilson, 2002). The episodic buffer strings the sounds and words together to form a connected, time-based sequence to hold the words together as a sentence (as when we are able to chunk a sequence of words). It is the episodic buffer that also accounts for how people remember lists of unrelated items (not in a sentence), which was described earlier as the serial position effect.

The concept of the episodic buffer helps us to understand an oddity in the clinical literature. There are individuals who suffer from a kind of amnesia that affects their short-term memory. Their memory span might be one or two unrelated words presented either aurally or visually. They can't repeat back more words than that and they have a great deal of difficulty understanding what is going on around them. However, if they are presented with words that form a sentence, the number of words they are able to repeat is often doubled (Baddeley & Wilson, 2002). This suggests that there is a sequencing process that is able to hold items together with a kind of time-based glue. This sequence works through the episodic buffer. The episodic buffer does not seem to have a unique area of the brain that performs its functions. It is probably redundantly represented in a number of places (Baddeley, 2002). This is sensible because the buffer is called upon to organize so many systems.

The Central Executive

According to Baddeley's model, working memory contains a fourth component, the **central executive**, which coordinates the activities of the visuospatial sketchpad, phonological loop, and episodic buffer, and also communicates with long-term memory via the episodic buffer (Baddeley, 1998, 2002). The central executive is not a memory store: It is a control system that guides attention and allocates resources to maximize performance. The attention system was discussed in Chapter 3 along with the basic spotlight metaphor. Sometimes the spotlight is moved by automatic processes and other times by more controlled processes. The central executive is the main system for controlling attention.

Researchers have designed a task to test the central executive's effectiveness in different people (Daneman & Carpenter, 1980, 1983; Daneman & Merikle, 1996). In this task, participants are supposed to read a series of short sentences and remember the last word of each sentence. Then they are tested on how many of the last words they are able to recall. The number of such words that a participant is able to recall reflects the ability of the central executive to control two tasks at once: reading sentences and remembering unrelated words. WM span, which basically determines WM efficiency (Turner & Engle, 1989), varies among people and correlates with standard measures of fluid intelligence (the ability to reason and make decisions on the fly; Kyllonen & Christal, 1990). As we will see in the chapters on language, WM span also predicts reading comprehension (Conway, Kane, & Engle, 2003; Swanson & Jerman, 2007).

The central executive coordinates, manipulates, and updates the content of the WM divisions (Baddeley & Logie, 1999). In general, executive functions, such as planning and paying attention, are centered in this area of the prefrontal cortex where the central executive is identified (see Figure 5.9). People who have damage to this region suffer an inability to plan an action (Owen, Evans, & Petrides, 1996), difficulty attending to relevant aspects of their environment, or difficulty handling multiple tasks at once (D'Esposito, Detre, Alsop, & Shin, 1995).

A test that measures central executive functioning is the Paced Auditory Serial Addition Task (PASAT; see **FIGURE 5.11**). The PASAT requires participants to add aurally presented consecutive numbers at a rate of about 2.4 seconds per number and announce the sum. This is more difficult than you might assume because the participant must not confuse the addition that he or she has just stated aloud with the next number presented. For example, if the first number is 4 and the second number is 6, the answer is 10. If the third number is 3, the answer is 9 (6 + 3). The participant must resist the temptation to say 13 (10 + 3; Gronwall, 1977).

A person's score on this test is the number of correct additions. This test makes only minor demands on arithmetic knowledge, but puts a premium on the individual's ability to do three things at once: add two numbers, keep track of the previously presented digit in working memory, and inhibit the sum of the previous two digits. The PASAT score relates to central executive functioning in the real world and is positively correlated with a person's level of vigilance: his or her ability to detect the presence of unlikely events (Weber, 1988). It also relates somewhat to a person's IQ (Spreen & Strauss, 1991; Wiens, Fuller, & Crossen, 1997). The PASAT has a diagnostic use: People who have recently suffered a concussion have greatly diminished PASAT performances (Erlanger, Kutner, Barth, & Barnes, 1999; Gronwall & Sampson, 1974).

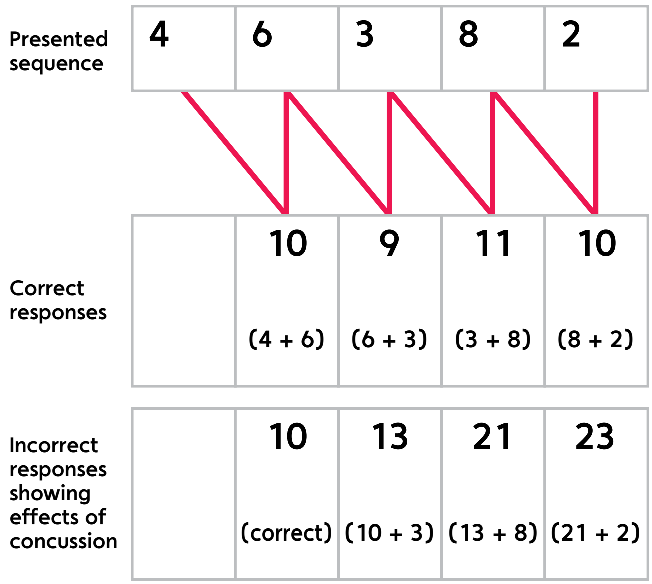


FIGURE 5.11 The PASAT Procedure The Paced Auditory Serial Addition Task (PASAT) measures central executive functioning. It requires participants to add aurally presented consecutive numbers at a rate of about 2.4 seconds per number and announce the sum. The difficulty is that the participant must not confuse the addition he or she has just stated aloud with the next number presented. The PASAT score relates to central executive functioning in the real world and is positively correlated with a person's level of vigilance. The test also has a diagnostic use: People who have recently suffered a concussion show greatly diminished PASAT performances.

Source: After Gronwall, 1977

It has already been mentioned that the PASAT is a measure of central executive functioning. Most studies indicate that both age and intelligence affect performance on the PASAT. In general, older people (50-year-olds) perform worse than younger people (20-year-olds), and those with higher IQ scores have stronger PASAT performance than those with lower IQ scores (Wiens et al., 1997). These effects suggest a biological basis for the efficiency of the central executive in working memory. Added to this is the effect of brain trauma on central executive functioning. Not only is the PASAT sensitive to the changes in cognitive functioning that result from concussions, it is also sensitive to more permanent cognitive damage following traumatic brain injury (Sohlberg & Mateer, 1989).

A word of caution is useful here. Although it is easy to point to the functioning of the frontal lobes as the location of the central executive, we must remember that the frontal lobes are connected to so many other areas of the brain that we can be confident neuropsychological research will show that additional areas outside the frontal lobes are likely to contribute to executive control.

SECTION SUMMARY

Working Memory: The Structure Beneath Short-Term Memory

Most cognitive researchers view short-term memory as reflecting a set of structures and processes called working memory. The working memory model consists of four divisions interacting with each other: the phonological loop, visuospatial sketchpad, episodic buffer, and central executive. The first three of these are limited-capacity memory structures that hold different representations of what we experience: sounds, visual and kinesthetic images, and sequential patterns that coordinate these representations. The central executive is responsible for attending to each of the memory systems and ensuring that any event we experience is properly coded so that it may be retained and used. Many functions of working memory are performed in the parietal lobe and prefrontal cortex. Neurological studies have shown that the processing of each subsystem is performed in distinct areas of the brain, except for the episodic buffer, which seems to be redundantly represented in a number of places because it participates in so many memory functions. Neuropsychological findings have provided evidence for the functional independence of the working memory systems.

Phenomena Explained by Working Memory

The following applications of the WM model illustrate how the four components of working memory function to explain three typical findings associated with STM: phonological confusions, word-length effect, and irrelevant speech effect.

Phonological Confusions

Phonological confusions occur when people try to remember lists of words or sentences (such as might occur in a poem) and find that their memory is worse for items that sound alike than for items that sound different. As a result, the person trying to remember a series of words or letters that sound alike will be judged to have a smaller STM span than a person trying to remember a sequence that does not sound alike. You can experience phonological confusion by trying Demonstration 5.5.

DEMONSTRATION 5.5

Phonological Confusions

Read aloud the string of seven letters in Set 1 as rapidly as you can, then close your eyes and try to recall the string of letters in the correct order.

Set 1: P-G-T-C-D-Z-B

Now do the same for Set 2.

Set 2: R-H-X-S-F-M-K

If you are like most adults, Set 1 felt like you were reading a tongue twister and typically takes longer to read than Set 2. How well were you able to remember each string? When people are asked to repeat back the letters, in exact order, Set 1 is more difficult to remember than Set 2.

Phonological confusion occurs not only when the letters are presented aloud, but also when they are presented visually (Conrad & Hull, 1964; Wickelgren, 1964). Working memory provides two explanations for these sound-based confusions. First, when the articulatory control process rehearses the phonological codes of the letters, it may confuse similar sounds and rehearse one sound or word more than the other because it can't tell which one it has already rehearsed. Second, these confusions occur even when the letters are visually presented because the central executive transfers a copy of the visual items to the phonological loop in the form of a phonological code. Once again, the articulatory control process becomes confused in its rehearsal of the sounds (Larsen, Baddeley, & Andrade, 2000).

Word-Length Effect

You have probably noticed that when you try to memorize vocabulary in a foreign language, the long words are more difficult to remember than the short ones. This pervasive phenomenon, investigated years ago by Hawkins and Shigley (1970), is termed the **word-length effect**: STM span decreases as the length of words to be memorized increases. For example, when students are asked to repeat one-syllable words like "mumps," "Maine," and "zinc," they are considerably more accurate than when they are asked to repeat words like "tuberculosis," "Yugoslavia," and "aluminum" (Baddeley, Thomson, & Buchanan, 1975). How does working memory explain this effect? Words with more syllables increase the number of sounds the articulatory control process must rehearse. Notice that long words not only have more syllables than short ones, they take longer to pronounce. To experience how time to pronounce affects your phonological loop, try Demonstration 5.6.

DEMONSTRATION 5.6

Word-Length Effect

Read the words in Set 1 aloud as rapidly as you can. As soon as you finish, write down all the words you can remember. Then, do the same for Set 2.

Set 1: COERCE, HUMANE, MORPHINE, MOONBEAM, ZYGOTE, BASEBALL, PAINTING

Set 2: TABLE, EMBER, HACKLE, PILLOW, WIGGLE, CLEVER, TENNIS

Did you remember more or fewer words from Set 1? The two sets of words have the same number of syllables. However, when you pronounced them aloud you should have noticed that the syllables in Set 1 take longer to say than those in Set 2. Pronouncing the syllables in Set 1 exceeds the roughly 2 seconds for the articulatory control process. As a result, most people remember more words from Set 2 than from Set 1.

To study the relationship between word length and the time to rehearse, Baddeley et al. (1975) created word sets that had the same number of syllables and letters, but took different amounts of time to pronounce in English, as is the case with the words in Demonstration 5.6. Participants were better at pronouncing and remembering words with short sounds (e.g., PICKET) than words with long sounds (e.g., PARLOR). A rule of thumb for estimating a person's memory span is: *If the articulatory control process can rehearse an item within 2 seconds, it will be retained in the phonological loop.* It is this time-based limitation imposed by the articulatory control process that sets the limit for the capacity of short-term memory. The typical memory capacity of 7 items, mentioned earlier in the chapter, is really the consequence of how long it takes to say the names of the items (e.g., Avons, Wright, & Pammer, 1994). For example,

A background conversation may reduce what you are able to recall after studying. This irrelevant speech effect happens only when the background sounds are the same as the sounds you are trying to remember: Speech interferes with reading but music does not.

Mandarin-speaking adults show a greater memory span for digits than do English-speaking adults (9.9 vs. 6.6 items). This perfectly coincides with how rapidly the two groups can articulate numbers. Mandarin speakers are faster at repeating numbers than English speakers (265 vs. 321 ms/digit; Ellis & Hennelly, 1980; Hoosain & Salili, 2005). Working memory shows that the speed of articulation is the key to the capacity of short-term memory.

Irrelevant Speech Effect

Suppose you are intensely studying a text and two people are having a conversation nearby. Although this background conversation is irrelevant to what you need to learn, it may reduce what you are able to recall in comparison to a situation when you are able to study in silence (Neath, 2000). The ability of inconsequential background speech to interfere with silent verbal rehearsal is called the **irrelevant speech effect** (Colle & Welsh, 1976). It can occur even when the language being spoken is different from the language of the text you are reading. This is because the speech sounds from the irrelevant speech enter the phonological loop and are added to the sounds associated with the words that you are trying to remember. Just like the word-length effect, sometimes the phonological loop holds so many speech sounds that the articulatory control process can't rehearse them in under 2 seconds.

Fortunately for people who like to listen to music when they study or balance their checkbook, the irrelevant speech effect occurs only when the irrelevant sounds are in the same category as those sounds that people are trying to remember: Speech will interfere with reading, but musical notes will not interfere with reading unless lyrics are embedded in the music (Salame & Baddeley, 1989). There are differences between men and women in the effect of lyrics and music: Women are more sensitive to the meaning of lyrics when they are embedded in music than men. The opposite is true when lyrics are presented in written form (Iverson, Reed, & Revlin, 1989).

SECTION SUMMARY

Phenomena Explained by Working Memory

Baddeley's model of working memory is able to explain many of the unusual phenomena associated with short-term memory: phonological confusion, word-length effect, and irrelevant speech effect. All of these effects are related to how WM codes what we see and hear and how the visuospatial sketchpad, the phonological loop, and the central executive retain information. All of these STM effects are connected to the way the articulatory control process of the phonological loop is able to maintain the viability of the information.

Working Memory and Emotion

Everyone experiences stressful events, but some life stressors are so extreme that they intrude unexpectedly into everyday thoughts and compete for working memory resources (Klein & Boals, 2001b). Efforts to suppress negative or stressful thoughts compete with WM resources to deal with ordinary tasks such as reasoning, remembering, and problem solving (e.g., Baradell & Klein, 1993). One reason for this is that emotional stimuli capture our attention and tell us they are important in ways that nonemotional stimuli often do not. This is called the *attentional capture hypothesis* (Yantis, 1993). These emotional stimuli could be anything from seeing a threatening face, reading a taboo word, or something that signals danger (e.g., Holmes, Vuilleumier, & Eimer, 2003; Mackay, Shafto, & Taylor, 2004; Taylor & Fragopanagos, 2005). Emotional events in our lives can be relentless in dominating our thoughts and consuming our WM resources (e.g., Mikels, Reuter-Lorenz, Beyer, & Frederickson, 2008). The relationship between emotional events, life stress, and WM capacity was examined in an experiment designed by Sarason, Johnson, and Siegel (1979). College students were asked to complete the Life Experiences Scale (Sarason et. al., 1979), which lists 47 significant life events (death of a family member, obtaining a new job, etc.). The students were also asked to take a WM test. On the test, students read a simple equation and marked the answer true or false. Each equation was followed by a different word that the student was expected to remember (e.g., "$4 \times 2 = 6$, back"). After reviewing sets of two to seven problems, students were asked to write down all the words paired with the equations that they could remember. The people with the greatest life event stress performed the poorest on this task. The higher the number of stressful events in one's life, the greater the demands on WM and the poorer the performance on WM-relevant tasks.

In a related study, Klein and Boals (2001a) asked college undergraduates to write either an essay about a negative event they had unwanted thoughts about, or an essay about a positive event in their lives. A control group of students was asked to write an essay about the day they were having. Students wrote for 20 minutes a total of three times over a 2-week period. At the end of the study, the students' WM capacity was measured and compared to their WM score when the study began. Students who had been asked to write about a negative event showed an 11% increase in WM capacity. Those who had written about a positive experience and those in the control group showed less than a 4% improvement in their WM score. This finding suggests that images of negative or traumatic experiences often intrude on our thoughts and tax WM's ability to inhibit the negative event so that we can focus on the tasks before us.

Writing the essay allowed the students to understand the negative emotional events and organize their thoughts about them. The negative thoughts were then less likely, in Klein's (2011) words: "to come unbidden to our conscious minds." This allowed the central executive to operate more efficiently on the

WM tasks, resulting in an improved score. Klein and Boals (2001b) further showed that this has a lasting effect. Those students who showed the greatest improvement in WM score also had the highest college grades a semester after the study was completed. These findings support the belief that emotions can tax the resources of the central executive and also underscore the possible value of keeping a diary.

The influence of emotion on the central executive can help explain cognitive impairments that are often attributed to neurological deficits. Cognitive impairments related to multiple sclerosis (MS) are a case in point. MS is a disorder of the central nervous system that results in the destruction of the white matter (in particular, the myelin) in the brain. More than a million people worldwide suffer from MS. In advanced stages of the disease, individuals with MS experience difficulty in processing information (Archibald & Fisk, 2000; Lengenfelder, Chiaravalloti, Ricker, & DeLuca, 2003). D'Esposito et al. (1996) asked participants with MS and a control group of healthy participants to perform concurrent tasks like judging the angle of lines while humming, tapping, or reciting the alphabet. The more difficult the concurrent task, the more impaired the participants with MS were in comparison with the control group.

Some of these findings may be the result of the negative emotions that individuals with MS experience as a result of their unpredictable and often debilitating condition, rather than neurological deficits resulting from the disease. In an independent test of depression and WM capacity, researchers found that depressed individuals with MS had a lower WM capacity than nondepressed individuals with MS or nondepressed individuals without MS (Arnett et al., 1999). This suggests that some of the effect of neurological diseases on WM may be a result of the emotional reaction and psychological state of the individual with MS, rather than a direct effect of the neurological damage.

Positive emotions should have a beneficial effect on WM because we know that happy moods are related to the flow of the neurotransmitter dopamine to the frontal lobes (Ashby, Isen, & Turken, 1999; Berk et al., 1989), which results in improved problem-solving abilities. However, positive moods do not seem to have as consistent an effect as negative moods. In one study, participants watched a comedy film or ate candy. As a result, they showed improvement in creative problem solving (Isen, Daubman, & Nowicki, 1987). However, the opposite results were shown in another study in which students, who watched a comedy film and experienced a positive mood as a result, showed poorer performance on tasks that required central executive functioning (Oaksford, Morris, Grainger, & Williams, 1996). Although positive moods have different effects on working memory, we know that negative moods diminish working memory. This may be because negative mood has a direct influence on blood flow to various regions of the brain having to do with memory and learning (e.g., Bush, Luu, & Posner, 2000; Liotti, Mayberg, McGinnis, Brannan, & Jerabek, 2002).

SECTION SUMMARY

Working Memory and Emotion

Our emotions interrupt the continuous flow of cognitive processes and affect the efficiency of working memory. In particular, negative thoughts compete for WM resources. The more stress in one's life, the lower the efficiency of WM in performing simple cognitive tasks. Students who performed exercises that reduced the intrusion of negative thoughts showed an increase in their WM capacity. The decline in WM capacity shown by some people with multiple sclerosis may be a result of their depression in reaction to having the disease, rather than to the direct effect of the neurological damage associated with the disease. Mood states (positive or negative) can have an influence on the neurotransmitter dopamine, which in turn can affect problem solving.

CHAPTER SUMMARY

Memory, broadly speaking, refers to our ability to retain information. Short-term memory (STM) is a memory system that allows us to retain items for a short period of time and may form the basis of our long-term memory and knowledge. STM is a limited-capacity system that increases from childhood to adulthood. The typical adult's STM span is between 5 and 9 unrelated items, called chunks. The amount of information that can be grouped as a chunk depends on whether a person is able to find a way of relating the items to one another and to what is already stored in long-term memory. People are able to retain information in STM for about 18 seconds without paying attention to it. Rehearsal (paying attention) helps to keep items in STM. There are two major types of rehearsal: maintenance and elaborative. Only elaborative rehearsal makes it easier to store new information in long-term memory. A major source of forgetting in STM is the interference among the items to be retained. The basis of interference is determined by the coding of the items. The major code in STM is sound based. People are able to verify the contents of their STM by using an exhaustive search procedure. The Sternberg task, which measures STM search, allows researchers to assess the effects of drugs and other treatments on memory.

Long-term memory and short-term memory interact when we try to remember a list of things in the precise order in which the list was presented. In this case, the proportion of the information we are able to recall tends to be related to the position of the items on the list. This phenomenon is called the serial position effect. According to the serial position effect, items at the beginning and end of a list are recalled more easily and accurately than items in the middle of the list. One way to overcome the power of the serial position effect is to make the information in the middle of a list more distinctive or to find a way to relate the items.

Short-term memory is a global term that describes a host of memory mechanisms that are called upon to help us interact with the world. An entire system of cognitive processes exists below the surface, which works to make STM visible and allows us to solve problems, make decisions, and remember and retrieve facts. This system is called working memory (WM). It is a multicomponent system composed of three limited-capacity subsystems: a phonological loop, a visuospatial sketchpad, and an episodic buffer. In addition, there is an attentional system called the central executive that coordinates the activities of the other subsystems. The coordination of these subsystems contributes to our smooth performance in reciting a poem or playing a sport, and explains selective impairments to memory that result from damage to various parts of the human brain, especially the frontal and parietal lobes.

WM components are able to explain three basic phenomena associated with STM. Phonological confusions result from similar sounding words being rehearsed by the articulatory control process in the phonological loop, as well as visually presented words in the visuospatial sketchpad. The word-length effect results from some words requiring more time to rehearse, which exceeds the refresh rate of the articulatory control process. The irrelevant speech effect occurs when unfiltered speech sounds enter into the phonological loop and therefore add more items to be rehearsed. Nonspeech sounds like a melody do not contribute to the irrelevant speech effect.

Human emotion can influence the flow of blood and neurotransmitters to brain areas that are critical for the optimal functioning of WM. Negative affect and depression can reduce WM capacity and interfere with cognitive performance. Positive mood has, in some cases, been shown to increase problem-solving effectiveness.

KEY TERMS

learning, p. 119
memory, p. 119
short-term memory (STM), p. 119
working memory (WM), p. 119
chunks, p. 122
chunking, p. 122
retroactive interference, p. 125
proactive interference, p. 125
rehearsal, p. 126
maintenance rehearsal, p. 126
elaborative rehearsal, p. 126
serial exhaustive search, p. 127
serial position effect, p. 130
primacy effect, p. 130
recency effect, p. 130
negative recency, p. 132
modality effect, p. 132
phonological loop, p. 135
phonological store, p. 135
articulatory control process, p. 135
visuospatial sketchpad, p. 136
visual cache, p. 137
inner scribe, p. 137
episodic buffer, p. 139
central executive, p. 140
phonological confusion, p. 142
word-length effect, p. 143
irrelevant speech effect, p. 144

QUESTIONS FOR REVIEW

Check Your Knowledge

1. What is the definition of learning?
2. What is the relationship between learning and memory?
3. State the three questions that scientists ask regarding short-term/working memory.
4. What are the answers to these questions with regard to STM?
5. Do children have the same STM capacity as young adults or older adults?
6. What is the memory span test?
7. What is a chunk and how is it related to STM capacity?
8. How is chunking helped by long-term memory?
9. What are the two categories of interference? Give an example of each one.
10. What are the two categories of rehearsal? Which one improves storage in LTM?
11. What search procedure do we use when we search our STM for a particular item?
12. If you graph the time to scan STM, what does the slope of the curve tell you?
13. If you are given a drug that doesn't affect the slope of the curve but only affects where the curve intercepts the vertical axis, what has the drug done?
14. When you read a paragraph and are tested on your recall of it right away, which part of the paragraph will you recall best: the beginning, middle, or end? What is this pattern called?
15. How can you improve your recall for the different parts of a paragraph?

16. What are the four main components of working memory?
17. In which portion of WM do we rehearse the sounds of words? What is the typical rehearsal rate for this part of WM?
18. How does the rehearsal rate affect STM capacity?
19. What are the two parts of the visuospatial sketchpad and what are their main functions?
20. Why does a concussion affect a person's ability to pay attention? What part of WM is affected by concussions?
21. What system is responsible for keeping track of steps in problem solving and where you are in a conversation?
22. What are phonological confusions?
23. What is the word-length effect?
24. What is the irrelevant speech effect?
25. How do our emotions affect our STM capacity?

Apply Your Knowledge

1. Using Baddeley and Hitch's theory of working memory, how can you account for the claim that adult STM capacity is 7 plus or minus 2?
2. The serial position effect is seen even when people are trying to remember the main points discussed in a paragraph. Design an instructional method to help students avoid falling prey to the effect when they are reading a textbook.
3. Some people are able to read with the radio or TV on in the background. This fact seems to conflict with the irrelevant speech effect predictions discussed in this chapter. Using what you have learned about the subsystems of working memory, explain how some people are able to avoid the effect.
4. As discussed in the text, some people with MS have difficulty with central executive functioning. This may be the result of an emotional reaction to a neurological problem rather than a direct physical effect of that problem. How might it be possible for a clinician to determine when memory difficulties result from emotional rather than physical causes?