Memory Components, Forgetting, and Strategies

CHAPTER 10

Concept: Memory storage and retrieval influence motor skill learning and performance.

After completing this chapter, you will be able to

- Compare and contrast *working memory* and *long-term memory* in terms of duration and capacity of information as well as processing activities in each
- Distinguish *procedural, episodic,* and *semantic* memory as components of long-term memory
- Define *declarative* and *procedural* knowledge
- Give examples of *explicit* and *implicit* memory tests and describe how each relates to assessing, remembering, and forgetting
- Discuss several causes of forgetting for working memory and long-term memory
- Discuss effective strategies to help remember a movement or sequence of movements that must be performed
- Define the *encoding specificity principle* as it relates to practice and test contexts associated with the performance of motor skills

APPLICATION

Have you ever had the experience of being introduced to someone at a party and then finding it difficult to recall that person's name, even a very short time later? Compare that to remembering a teacher's name from your elementary school. You can probably name most of your teachers with little difficulty. The situations described so far relate to our use of memory for cognitive or verbal information. Now let's consider a situation involving a motor skill. If you took tennis classes as a beginner (if you haven't taken tennis classes, substitute any physical activity or sport skill you have experienced as a beginner), think about the time when you were shown how to serve a tennis ball for the first time. When you tried it, you found that you had some difficulty remembering all the things that you were supposed to do to perform a successful serve. Think about how remembering in that situation differs quite drastically from how well you can hop onto a bicycle, even after you have not been on one for many years, and ride it down the street.

Application Problem to Solve Describe a motor skill that you might help people learn. When you give them instructions about how to perform the skill, or specific parts of the skill, how will you give those instructions so that the people will remember what they are supposed to do when they practice the skill?

DISCUSSION

Memory plays an important role in virtually all our daily activities. Whether in conversation with a friend, working mathematical problems, or playing tennis, we are confronted by situations that require the use of memory to produce action.

What is memory? We often think of memory as being synonymous with the words *retention* or *remembering*. As such, most people consider that the word *memory* indicates a capacity to remember. Endel Tulving (1985), a leading contemporary memory researcher and theorist, has stated that *memory* is the "capacity that permits organisms to benefit from their past experiences" (p. 385).

In the discussion that follows, we will consider various issues and questions concerning human memory as it applies to the learning and performance of motor skills. First, we will discuss the different storage systems included in memory. We will then build on this foundation by considering the issue of the causes of forgetting and finally will address how these causes can be overcome by the use of strategies that can help develop a more durable and accessible memory for the skills being learned.

MEMORY STRUCTURE

Views about the structure of memory have gone through many different phases throughout the history of the study of memory, which can be traced back to the early Greek philosophers. However, one characteristic of memory structure that is now commonly accepted is that a part of memory is oriented toward events that have just occurred, while a part is related to events in the past. This is not a new idea. In fact, in 1890, William James wrote of an "elementary" or "primary" memory that makes us aware of the "just past." He distinguished this from a "secondary memory" that is for "properly recollected objects." To primary memory, James allocated items that are lost and never brought back into consciousness, whereas to secondary memory, he allocated ideas or data that are never lost. Although they may be "absent from consciousness," they are capable of being recalled.

The debate about the structure of memory has centered on how this distinction between memory for immediate things and memory for things in a more distant past fits into a structural arrangement. At present, the bulk of the evidence supports the view that there are two components of memory.[1] The evidence for this comes from two different but complementary research approaches to the study of human memory. One of these is taken from the study of cognitive psychology, where inferences about the structure and function of memory are based on observing the behavior of individuals in memory situations. The other approach is that of the neuropsychologist or neurophysiologist, who is interested in explaining the structure of memory in terms of what is occurring in the nervous system during behavioral changes related to memory. Research evidence from both of these approaches provides convincing evidence that the memory system comprises at least two components that are definable by their distinct functions. Also, it is important to note that after reviewing and evaluating the relevant research literature, Healy and McNamara (1996) concluded that although some elaboration of various aspects of the component model of memory is needed, the model remains a useful means of understanding human memory.

A Two-Component Memory Model

Several different models of human memory have been developed to represent its component structure. One of the most enduring and influential was presented by Atkinson and Shiffrin in 1968. Using a computer analogy, they conjectured that memory structure should be thought of as similar to computer hardware. They considered that the software that allows the computer to function constitutes the "control processes," which involve memory processes such as storage and retrieval of information and are

[1]Although some models and discussions of memory include "sensory memory" as a third component, its role in motor skill learning and performance has not been well established. As a result, it is not included in this discussion.

under the control of the person. The structural components, they concluded, comprise a sensory register, short-term store, and long-term store.

Since the time of Atkinson and Shiffrin's presentation of theory of memory structures, the primary theoretical problem has been to determine the exact nature of these structures. While debate continues about memory structure, there is general agreement that this structure of memory should include different memory storage components in addition to serving a functional role for what the person does with the information in each component. (To read a brief overview of the neuroscience debate about memory structure, see Nee, Berman, Moore, & Jonides, 2008.)

An excellent example of a memory structure model that accommodates these characteristics was proposed by Baddeley (1986, 1995, 2003, 2012). According to this view, memory is seen as comprising two functional systems, *working memory* and *long-term memory* (see figure 10.1). Each memory system is defined in terms of its functions. Although a number of different functions have been proposed, we will focus primarily on three: putting information in memory (referred to as storage processes), getting information out of memory (referred to as retrieval processes), and specific functions in each component.

WORKING MEMORY

The **working memory** should be thought of as a system that incorporates characteristics and functions traditionally associated with sensory, perceptual, attentional, and short-term memory processes. Working memory operates in all situations requiring the temporary use and storage of information and the execution of memory and response production processes (see Baddeley, 1995). Baddeley (2003) stated that the working memory is a limited capacity system, which temporarily maintains and stores information and provides "an interface between perception, long-term memory, and action" (p. 829). As such, working memory includes memory functions traditionally ascribed to *short-term memory,* as well as other functions

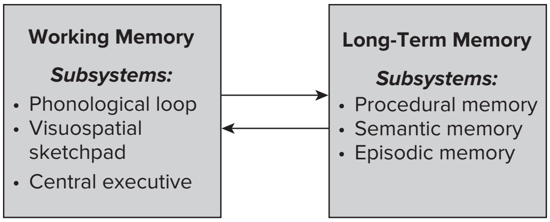

FIGURE 10.1 A schematic diagram of the working memory and long-term memory systems with the subsystems identified for each. The arrows represent the interactive nature of the two systems.

typically associated with the attention-related processes we discussed in chapter 9 (Engle, 2002).[2]

Working Memory Functions

Working memory is both a place where information is stored for a short time and a functionally active structure. These two characteristics of working memory enable people to respond according to the demands of a "right now" situation. To do this, *working memory plays a critical role in decision making, problem solving, movement production and evaluation, and long-term memory function.* With regard to influencing long-term memory function, working memory provides essential processing activity needed for the adequate transfer of information into long-term memory. Finally, it is important to note that an important working memory function is to serve as an *interactive workspace* where various memory processing activities can occur, such as integrating the information in working memory with information that has been retrieved from the more permanent, long-term memory.

[2]For a brief review of evidence that identifies neural mechanisms associated with working memory, see Smith (2000).

working memory a functional system in the structure of memory that operates to temporarily store and use recently presented information; it also serves as a temporary workspace to integrate recently presented information with information retrieved from long-term memory to carry out problem-solving, decision-making, and action-preparation activities.

A CLOSER LOOK

Pitching in Baseball: A Demonstration of the Interactive Workspace Function of Working Memory

The situation. You are a baseball catcher or coach who needs to decide which pitch the pitcher should throw next. To make this decision, you must consider information about both the present situation and past experiences. In terms of the present situation you need to consider *who the batter is, the score, who and where the runners on base are, the number of outs, the locations of defensive players in the infield and outfield, the ball and strike count,* and so on. In terms of past experiences you need to consider *the batter's batting history in similar situations, the opposing team's tendencies in this situation—especially if they have runners on base—the pitcher's history of pitching in similar situations,* and so on.

Working memory involvement. The working memory serves as a temporary workspace to enable you to integrate the information about the present situation and past experiences so that you can select the best pitch for right now. After receiving your pitch choice, the pitcher will involve the working memory to retrieve from long-term memory the invariant characteristics of the type of pitch required and then use the temporary workspace to apply specific movement-related features to the pitch, such as speed and location. After the pitch is delivered, the information in working memory is deleted to provide space for new information to allow the pitcher to respond to what the batter does or to throw the next pitch you select.

According to Baddeley's conception of working memory, its functions are related to three subsystems. The first two subsystems store different types of information. One is the *phonological loop,* which is responsible for the short-term storage of verbal information. Second is the *visuospatial sketchpad*, which stores visually detected spatial information for short periods of time. The third subsystem, the *central executive,* coordinates the information in working memory, which includes information retrieved from long-term memory. Neurologically, these components of working memory are localized in various brain regions, including the parietal cortex, Broca's area, premotor cortex, occipital cortex, and the frontal cortex (Baddeley, 2003).

Researchers have also proposed that a fourth subsystem might exist in working memory, the *motor store* (e.g., Jaroslawska, Gathercole, & Holmes, 2018). It is not clear whether the proposed motor store is a separate subsystem in working memory or a component of the visuospatial sketchpad, perhaps encoding kinesthetic information. Evidence for the motor store comes from experiments showing a distinct advantage for the verbal recall of action sequences when participants perform the sequences during encoding or anticipate having to perform them during recall. This advantage is known as the *action advantage* (e.g., Waterman et al., 2017). For example, a sequence like "pick up the cup, point to the pencil, slide the ruler, and point to the paper" will be recalled more accurately verbally when participants perform the sequence in addition to either seeing it performed or hearing it described than when they only hear it or see it (Jaroslawska et al., 2018). Researchers are currently exploring how the proposed motor store might lead to a reconceptualization of Baddeley's description of working memory.

Because working memory stores and processes information, it is important to consider each function separately. In terms of storing information, two characteristics of working memory are essential to understand: the length of time information will remain in working memory, which is called *duration,* and the amount of information that will reside in working memory at any one time, which is called *capacity.*

Duration

Our understanding of the duration of information in working memory comes from research that investigated short-term memory. Peterson and Peterson (1959) were the earliest to report research related to the remembering of words presented one time each. They showed that we tend to lose information (i.e., forget) from working memory after about only

A CLOSER LOOK

Experimental Procedures to Assess the Duration of Movement Information in Working Memory

The classic experiment by Adams and Dijkstra (1966) set the standard for the procedural protocol researchers have used to investigate the question concerning the duration of movement information in working memory. Because the researchers were interested in movement information, their procedures were designed to require participants to use only proprioceptive information to perform the task.

- **Apparatus.** An arm-positioning apparatus consisted of an almost friction-free handle that could be moved left or right along a metal trackway. This apparatus sat on a table facing the participant in the experiment.
- **Task.** To begin a trial, a blindfolded participant moved the handle of the apparatus along the trackway to a location specified by a physical block (the criterion arm position to be remembered). After returning the handle to the starting point and waiting for a certain amount of time (the retention interval), the participant performed a recall test by moving the handle to his or her estimate of the arm position just experienced (the physical block had been removed). The experimenter recorded the location and the participant returned the handle to begin a new trial, which involved moving to a new position along the trackway.
- **Determining duration.** To determine the length of time movement location information stayed in working memory, the researchers compared various durations of the retention interval. They determined the accuracy of the participants' recall movements for each retention interval length. Duration of the memory for the arm position was assumed to be related to the degree of accuracy of the recall movement. As you can see in figure 10.2 below, arm-positioning recall accuracy decreased (i.e., error increased) very sharply for retention intervals up to 20 sec, and continued to decrease for longer interval lengths.

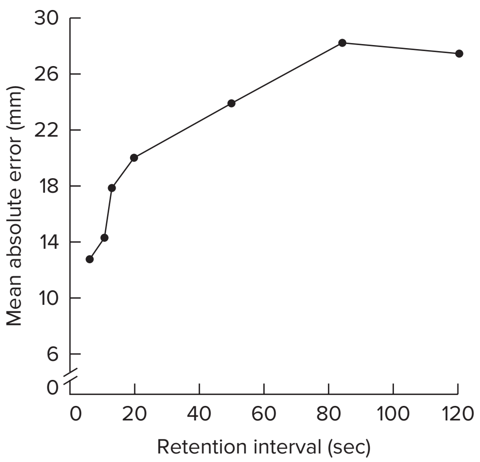

FIGURE 10.2 Results from the experiment by Adams and Dijkstra showing the mean absolute error for the recall of an arm-positioning task following different lengths of retention intervals. *Source:* From Adams, J. A., & Dijkstra, S. (1966). Short-term memory for motor responses. *Journal of Experimental Psychology, 71,* 314–318.

20 to 30 sec. The first experiment published relating working memory storage duration to motor skills was by Adams and Dijkstra in 1966. Their experiment indicated that arm positions in space that are experienced one time each are lost from working memory at a rate comparable to that of words.

The results of many other studies that followed the Adams and Dijkstra investigation generally supported the conclusion that the duration of movement information in working memory is about 20 to 30 sec. Information that is not processed further or rehearsed is lost.

Capacity

We are concerned with not only *how long* information will remain in short-term storage, but also *how much* information we can accommodate. The issue of capacity in working memory was originally presented by George Miller in 1956, in an article that has become a classic in the memory literature. Miller provided evidence to indicate that we have the capacity to hold about *seven items (plus or minus two items),* such as words or digits, in short-term storage. To increase the "size" of an item in memory involves a control process termed *organization,* which we will consider later in this discussion. The newly created larger item, or "chunk" as Miller called it, enables people to recall far more than five to nine individual items at a time. However, research has shown that although the size of a chunk may increase, working memory's capacity for storing them remains constant at about seven (Cowan, Chen, & Rouder, 2004; Mathy & Feldman, 2012). Thus in terms of storage capacity, items maintained in working memory can vary in size. One of the problems researchers have experienced in investigating the capacity limit of working memory is determining how to objectively define and measure an "item" or chunk.

The definition and measurement problem has been especially problematic for researchers interested in motor skills who are interested in testing Miller's capacity hypothesis in terms of the remembering of movements. In spite of this problem, a few researchers have reported investigations of the capacity limits of working memory for movements. In general, their results agree with the 7 ± 2 range proposed by Miller. For example, in one of the first investigations of this issue, Wilberg and Salmela (1973) reported that an eight-movement sequence of arm-positioning movements was the upper limit of working memory capacity for movements. In another study, Ille and Cadopi (1999) asked twelve- and thirteen-year-old female gymnasts to reproduce a sequence of discrete gymnastics movements after watching the sequence one time on a videotape. The gymnasts' recall performance demonstrated a six-movement capacity limit for the more-skilled gymnasts and a five-movement limit for the less-skilled gymnasts. The results for these young gymnasts are in line with those reported by Starkes, Deakin, Lindley, and Crisp (1987) for young skilled ballet dancers, who showed evidence that an eight-movement sequence was their capacity limit.

To account for research evidence that has shown that highly skilled individuals (i.e., experts) seem to have a working memory capacity that is greater than that of the general population, Ericsson and Kintsch (1995) proposed a memory mechanism they called *long-term working memory.* In addition to having a larger working memory storage capacity, experts also show evidence that performing certain secondary tasks does not interfere with their performance of the activity at which they are skilled. Experts in an activity use long-term working memory when they must have access to a large amount of relevant knowledge at their disposal to use while performing the activity. In addition, the experts use long-term working memory to integrate new information with previously acquired knowledge. It is important to note that as is commonly characteristic of expertise (which we will discuss more fully in chapter 12), long-term working memory is skill specific, which means that it develops as expertise in a skill rather than being a common component of working memory.

Processing Activities

Information that is active in working memory is processed (or manipulated) in such a way that it can be used to achieve the goal of the problem at hand. The goal may be to remember what you have just been told or shown to do so that you can do the task. Or you may need to use this information to solve a specific movement problem. And in both cases, you would like to remember what you did in each performance situation so that you can use your experience as a reference to help you in some future performance situation. In each case, you will involve working memory processing activities to enable you to achieve different goals.

Consider some examples of motor skill performance situations in which these different working memory processing activities could occur. Suppose your golf instructor has just given you a specific instruction to concentrate on your hand position as

A CLOSER LOOK

The Influence of Emotion on Memory of an Event: Recalling Details of Two Yankees versus Red Sox Championship Games

A study by Breslin and Safer (2011) presented an interesting approach to providing evidence that positive and negative emotionally arousing experiences are recalled more accurately than experiences where neither emotion is involved. More than 1,500 baseball fans who reported having attended, watched, or read about the 2003 and 2004 American League Championship games between the New York Yankees and Boston Red Sox (a well-known rivalry even when no championship is at stake) were asked to complete a questionnaire about each game. The participants were identified as Yankee fans, Red Sox fans, or neutral in their support for either team.

Method and questionnaires: Prior to answering the questionnaires about the games, the participants were each reminded that the Yankees won the 2003 game and the Red Sox won the 2004 game. The questionnaires asked participants to recognize and recall details about the two games and to rate their own subjective memories about the games. The items of interest to the researchers, which were identical on each questionnaire, asked:

- What was the final score of each game?
- Who were the winning and losing pitchers for each game? (a multiple-choice list)
- What was the location of each game (New York or Boston)?
- Did the game require extra innings?

Results: The following were the main results of this study:

- The correct responses to the questions showed similar accuracy for all the participants.
- Accuracy was higher for the fans that supported one of the teams than for the neutral fans.
- Yankees fans recalled more details accurately for the game the Yankees won.
- Red Sox fans recalled more details accurately for the game the Red Sox won.
- Fans reported remembering the game their team won more vividly than the game their team lost.
- Fans reported thinking about the game their team won since the time of the game.

Conclusion: Consistent with research of autobiographical memories, most individuals relive and recall more often and vividly memories that are positive rather than negative.

you swing a golf club. You must not only remember this instruction as you swing, but also retrieve from long-term memory the correct hand position and evaluate your present hand swing compared with the ideal. Of course, how successfully you make this comparison on your own depends on your stage of learning. But carrying out this verbal instruction invokes the working memory.

Suppose you have just watched a dancer perform a sequence of dance movements and you must now perform that sequence. Working memory processing activity would be involved because you must keep in memory the visually presented sequence of movements and translate that visual information into motor performance. Involved in this translation process would be retrieving from long-term memory the movement information required to carry out the sequence.

Consider also the following example. You are a patient in an occupational therapy session and are given a complex puzzle to put together. You study the pieces and try to determine how the specific pieces fit together. You continually try to match pieces as in the completed puzzle. And you try to determine an appropriate movement strategy that would allow you to put the pieces together quickly and with little error. Working memory would be actively involved in this problem-solving situation because you carried out several activities requiring several different perception, remembering, and performance characteristics that must be done virtually simultaneously.

LONG-TERM MEMORY

The second component system in the memory structure is **long-term memory**, which is a more permanent storage repository of information. It is what we typically think of when the term *memory* is mentioned. William James (1890) considered long-term memory as "memory proper." This is the component of memory that contains information about specific past events as well as our general knowledge about the world.

In terms of the *duration* of information in long-term memory, it is generally accepted that the information resides in a relatively permanent state in long-term memory. Usually, "forgotten" information that is stored in long-term memory is there, but the person is having difficulty locating it. Thus, measuring forgetting and remembering in long-term memory situations can be a tricky problem. We will come back to this important point later in this chapter.

With regard to the *capacity* of long-term memory, it is generally agreed that there is a relatively unlimited capacity for information in long-term memory (e.g., Chase & Ericsson, 1982). In fact, we know neither how much information a person can store in memory nor how to measure the capacity of long-term memory. An unlimited capacity leads to unique problems, however. For example, organization of information in memory becomes much more critical in an unlimited capacity system than in one of a limited capacity. Thus, there is a need to understand how people organize the information stored in long-term memory. This and other related issues unique to long-term memory will be discussed throughout this chapter.

In terms of information duration and capacity characteristics, it becomes obvious that long-term memory is distinct from working memory. Another distinct characteristic of long-term memory is the type of information that is stored there. In the following sections, three types of information stored in long-term memory will be discussed.

Procedural, Semantic, and Episodic Memory

In a commonly referred-to model of long-term memory, Tulving (1985) proposed that there are at least three "systems" in long-term memory: *procedural, semantic,* and *episodic* memories. Each of these systems differs in terms of how information is acquired, what information is included, how information is represented, how knowledge is expressed, and the kind of conscious awareness that characterizes the operations of the system. We will briefly consider each of these systems and how they function and differ.

Procedural memory. This memory system may have the most direct relevance to our discussion of long-term memory because it relates specifically to storing and retrieving information about motor skills. Procedural memory is best described as the memory system that enables us to know "how to do" something, as opposed to enabling us to know "what to do." This distinction is readily seen in situations where you can perform a skill very well (i.e., "how to do it"), but you are not able to verbally describe very well what you did (i.e., "what to do").

The procedural memory system enables us to respond adaptively to our environment by carrying out learned procedures so that we can achieve specific action goals. For the performance of motor skills, procedural memory is critical because motor skill is evaluated on the basis of producing an appropriate action, rather than simply verbalizing what to do. According to Tulving, an important characteristic of procedural memory is that procedural knowledge can be acquired only through "overt behavioral responses," which, for motor skills, means physical practice.

Semantic memory. According to Tulving (1985), semantic memory can be characterized by "representing states of the world that are not perceptually present" (p. 387) to us right now. This means that we store in this memory system our *general knowledge* about the world that has developed from our many experiences. This includes specific factual knowledge, such as when Columbus reached America or the name of the tallest building in America, as well as conceptual knowledge, such as our concepts of "dog" and "love." How information is represented in semantic memory is currently the source of much debate. The debate ranges from suggestions that all experiences

Hitting a forehand groundstroke during a rally in tennis requires the player to know what to do in the situation and how to execute the stroke.

Karl Weatherly/Getty Images

are represented in some fashion in memory to suggestions that individual experiences are not represented in semantic memory, but rather, only abstractions, such as prototypes or schemas, are represented.

Episodic memory. We store in episodic memory our knowledge about personally experienced events, along with their temporal associations, in subjective time. It is this memory system that enables us to "mentally 'travel back' in time" (Tulving, 1985, p. 387). Tulving views episodic memory as "oriented to the past in a way in which no other kind of memory, or memory system, is" and as "the only memory system that allows people to consciously reexperience past experiences" (Tulving, 2002, p. 6). An example here would be your memory of an important life event. You are very likely to recall this event in terms of both time and space. For example, if you were asked, "Do you remember your first day of school?" you would retrieve that information from episodic memory. Episodic memory is usually expressed in terms of remembering some experience, or episode. When a person recalls an experience from episodic memory, it is a personal recollection of the event. Tulving (2002) also described episodic memory as a memory system that deteriorates easily and is more vulnerable than other memory systems to neural dysfunction. For performing motor skills, episodic memory can be the source for information that prepares you for an upcoming performance or helps you determine what you are now doing wrong that at one time you did correctly.

Distinguishing between Knowing What to Do and Doing It

An important part of relating the three memory systems of long-term memory with the learning and performance of motor skills is the distinction between knowing what to do and knowing how to do it. Some learning theorists have argued that the information in the episodic and semantic memory systems should be considered **declarative knowledge** (e.g., Anderson, 1987). This knowledge is specified as what we

long-term memory a component system in the structure of memory that serves as a relatively permanent storage repository for information.

declarative knowledge knowledge about what to do in a situation; this knowledge typically is verbalizable.

are able to describe (i.e., declare) if we are asked to do so. Thus, declarative knowledge is specific to knowing what to do in a situation. This type of knowledge is distinct from *procedural knowledge,* which typically cannot be verbalized or is difficult to verbalize. As described earlier, **procedural knowledge** enables the person to actually perform a skill. This distinction is a useful one and will be referred to in various parts of this chapter.

One of the few experiments that has directly distinguished these two types of knowledge as they relate to motor skill performance provides an excellent example of the difference between declarative and procedural knowledge. McPherson and Thomas (1989) classified nine- to twelve-year-old boys as “expert” or “novice” tennis players based on length of playing experience and tournament play. Novices had only three to six months playing experience. The “experts,” who had at least two years of experience and had played in junior tournaments, were in an elite group for their age. The players were interviewed after each point (something that the researchers had previously established did not disrupt the quality of performance). Players were asked to state what they had attempted to do on the previous point. When this information was later compared with what they had actually done (which was analyzed from a videotape recording), some interesting results were obtained. First, in terms of having an effective strategy or action goal, the experts knew what to do nearly all the time, whereas the novices generally never knew what to do. Second, although the experts were quite capable of demonstrating that they knew what action goal to establish in a specific situation, they were not always able to accomplish it in their performance of the action. This suggests that the appropriate goal was established but there were problems in the physical execution of the intended action.

A different approach to demonstrating the distinction between declarative and procedural memory is to show that people with memory impairment due to amnesia can learn to perform a motor skill despite evidence of impaired declarative memory related to the task. An example of this type of experiment was reported by Cavaco, Anderson, Allen, Castro-Caldas, and Damasio (2004); chronic amnesic patients were compared to matching normal participants in learning to perform five tasks that were based on real-world experiences, such as weaving fabric, tracing geometric figures, and pouring water into cylinders. The results showed that the amnesic patients improved performance on all five tasks during practice trials and maintained improved performance levels 24 hours and 2 weeks later. In fact, their performance levels were comparable to the normal control participants. However, when the amnesic patients were given declarative memory tests as part of the 24-hour retention test, they performed much worse than the normal participants and showed no explicit recall of characteristics of any of the five tasks they had practiced.

REMEMBERING AND FORGETTING

A variety of reasons exist to explain forgetting. But before discussing some of those reasons, some terms need to be identified and defined. **Encoding** is the transformation of information to be remembered into a form that can be stored in memory. *Storage* refers to the process of placing information in long-term memory. *Rehearsal* is a process that enables the individual to transfer information from the working memory to long-term memory. **Retrieval** involves the search through long-term memory for information that must be accessed and used in order to perform the task at hand.

ASSESSING REMEMBERING AND FORGETTING

Researchers generally determine what or how much has been remembered or forgotten by using one or both of two categories of memory tests.

Explicit Memory Tests

When we ask people to remember something, we are asking them to consciously call something to mind. Tests of memory that do this same type of thing are known as *explicit* memory tests. These tests assess what a person can *consciously remember.* Two types of explicit memory tests that have been

A CLOSER LOOK

Typical Explicit Memory Test Paradigms Used in Experiments to Assess Remembering and Forgetting

Researchers who investigate the causes of forgetting and remembering typically use procedures that follow three basic paradigms, depending on whether they are interested in the effects of time or activity. These paradigms are illustrated below from the participant's point of view in terms of the events that take place at specific times during the experiment.

Paradigm to Test the Effect of TIME

Perform movement(s)/skill to be remembered — - - -Rest/No activity- - - [RETENTION INTERVAL] — Perform the memory test

Time →

Paradigm to Test the Effect of PROACTIVE INTERFERENCE

- - -Perform activity- - - — Perform movement(s)/skill to be remembered — [RETENTION INTERVAL] — Perform the memory test

Time →

Paradigm to Test the Effect of RETROACTIVE INTERFERENCE

Perform movement(s)/skill to be remembered — - - -Perform activity- - - [RETENTION INTERVAL] — Perform the memory test

Time →

popular in memory research are known as recall tests and recognition tests.

A **recall test** requires a person to produce a required response with few, if any, available cues or aids. This test asks the person to "recall" information that has been presented. In the verbal domain, these tests typically take the form of essay or fill-in-the-blank tests. For example, a recall test could ask, "Name the bones of the hand." For motor skills, a recall test requires the person to perform an action on command, such as "Perform the skill I just demonstrated to you" or "Show me how you tie your shoe."

A **recognition test**, on the other hand, provides some cues or information on which to base a response. In this type of test, a person's task is to recognize the correct response by distinguishing

procedural knowledge knowledge that enables a person to know how to do a skill; this knowledge typically is difficult to verbalize or is not verbalizable.

encoding a memory process involving the transformation of information to be remembered into a form that can be stored in memory.

retrieval a memory process involving the search through long-term memory for information needed to perform the task at hand.

recall test an explicit memory test that requires a person to produce a required response with few, if any, available cues or aids.

recognition test an explicit memory test that requires a person to select a correct response from several alternative responses.

it from several alternatives. In the verbal domain, multiple-choice or matching tests are examples of recognition tests. For example, you could be asked, "Which of these is a bone of the hand?" You are then given four alternative answers from which to choose, where only one is correct. To answer the question, you need only to recognize which is the correct alternative, or which are the incorrect alternatives. For motor skills, an example for a *movement recognition test* would involve having a person produce several different movements and then asking which of these is the one just demonstrated or most appropriate for a specific situation.

In terms of learning and performing motor skills, we are often confronted with both recall and recognition "tests," sometimes in the same situation. For example, if a person must climb a ladder, he or she must *recall* what to do and how it should be done in order to safely and effectively climb the rungs to the desired height. When the person then climbs the ladder, he or she must recognize that the movements performed are the same as those he or she recalled. In a sport context, when a baseball or softball batter must decide whether or not to swing at a pitch, he or she engages in a recognition test when determining if the ball is in the strike zone or not. Then, to produce the appropriate swing, the batter must recall what to do to carry out this action and then be able to recognize if the swing that has been initiated is appropriate for hitting the pitch where it is thrown.

An important benefit of recall and recognition tests is that each provides different information about what has been remembered or forgotten. It is possible for a person to fail to produce a correct response on a recall test, but be able to produce that response when it is one among several alternatives in a recognition test. A value of the recognition test, then, is that it enables the researcher to determine if information is actually stored in memory, even though retrieval cues or aids are needed by the person in order to gain access to that information.

Implicit Memory Tests

Many times people have information stored in memory, but it is stored in such a way that they have difficulty accessing that information so that they can respond correctly on explicit memory tests. This type of situation is especially relevant for procedural memory, which we discussed earlier as one of the long-term memory systems. For example, suppose you were asked to describe the grammatical rules of a sentence you had just said. Although you may not have been able to identify these rules, you confirmed your knowledge of them by the sentence you articulated. As a result, you demonstrated that you had knowledge about grammar rules stored in memory, but in a form that could not be brought to a conscious level so you could verbalize the rules.

For motor skills, we can assess implicit memory by asking a person to verbally describe how to perform a skill and then asking him or her to perform it. As is often the case, especially with highly skilled people, the person can successfully perform a skill but cannot verbally describe what he or she did. For example, if you were asked to verbally describe how you tie your shoes without using your hands, you might not be able to do it, or you might experience some difficulty doing it. Does this mean you don't know how to tie your shoes or that you have forgotten how to tie your shoes? No; in terms of our earlier distinction between procedural and declarative knowledge, it means that you do not have access to, or immediate access to, your declarative knowledge about tying shoes. How would you provide evidence that you know how to tie your shoes? You would physically demonstrate tying your shoes, which would indicate that you had the procedural knowledge necessary to perform this skill.

On the other hand, it is possible to know what to do (i.e., have declarative knowledge), but not be able to actually do what you know you should do (i.e., have poor procedural knowledge). This phenomenon was demonstrated very nicely in another experiment by McPherson and Thomas (1989), which was related to the one discussed earlier. They also gave young male basketball players an explicit paper-and-pencil test and asked them to indicate what they would do in a given basketball game situation. This information indicated declarative knowledge about what to do. An implicit test was also administered by observing what the players actually did in a situation to determine if they had the procedural knowledge necessary to do what they indicated should be done. The results showed that many of the players knew what to do in each situation, but couldn't actually do it in a game.

THE CAUSES OF FORGETTING

Trace Decay

When forgetting occurs with the passing of time, the cause is generally termed *trace decay* in the memory literature. It should be noted that the term "trace" is not commonly used in contemporary memory research literature. However, it can be thought of as synonymous with what is referred to in this discussion as the memory representation of an action.

An important point about trace decay is that it can be effectively tested as a cause of forgetting only in working memory. However, for long-term memory, a major problem is the practical impossibility of maintaining a no-interference test situation. For example, if you try to recall how to hit a slice serve in tennis after several years of not having performed it, you will have some initial difficulty remembering how to do it. Although time is a factor, you undoubtedly experienced the potentially interfering influences of the many cognitive and motor activities you have performed since you last performed this type of serve. Hence, we observe the interaction of interference and time in the long-term memory situation. As a result, we know very little about the influence of time on forgetting information stored in long-term memory.

Although time undoubtedly influences forgetting of information stored in long-term memory, it is more likely that forgetting involves the misplacing of information or interference from other activity rather than its decay or deterioration. One reason for this is the relative permanence characteristic for information stored in long-term memory. Thus, forgetting typically refers to a retrieval problem rather than to information no longer in memory.

Proactive Interference

Activity that occurs *prior to* the presentation of information that is to be remembered and negatively affects the remembering of that information is known as **proactive interference**.

Proactive interference in working memory. Relatively convincing research evidence suggests that proactive interference is a reason for forgetting movement information held in working memory. One of the best examples of this was provided in an experiment by Stelmach (1969) many years ago. Participants moved to either zero, two, or four locations on an arm-positioning task *before* moving to the location to be recalled. Following a retention interval of 5, 15, or 50 sec, they moved in reverse order to their estimates of each of the locations they had moved to. Thus, the first location recalled was the criterion location. Results showed proactive interference effects as four prior movements and a retention interval of at least 15 sec yielded the largest amount of recall performance error, compared to the other time and activity conditions.

Several attempts have been made to explain why proactive interference affects remembering movement information. One plausible suggestion is that when the proactive interference takes the form of other movements, especially those that are similar to the criterion activity, *confusion* occurs. The individual is unable to make the criterion movement precisely because of the influence of the prior activities on the distinctiveness of the criterion movement.

Proactive interference seems to occur primarily when there is similarity between what is to be remembered and the interfering activity. This similarity seems to relate to "attribute" similarity. That is, if the information to be remembered and the interfering activity relate to the same movement attribute or characteristic, then proactive interference will build up as the number of similar movements preceding the movements to be remembered increases. For example, several studies by Ste-Marie and her colleagues in Canada have shown that gymnastics judges demonstrate proactive interference effects by exhibiting a judging bias during actual competition based on what they observed a gymnast

proactive interference a cause of forgetting because of activity that occurs prior to the presentation of information to be remembered.

A CLOSER LOOK

Proactive Interference Influences Gymnastics Judging

A series of studies by Diane Ste-Marie and her colleagues provide interesting evidence that gymnastic judges' evaluations of a gymnast's performance may be influenced by their having watched the gymnasts during pre-competition warm-up sessions. In each study, the following procedures were used:

Participants: Female gymnastics judges certified by Gymnastics Canada

Study phase: The judges watched videotapes of individual gymnastic elements performed by several gymnasts. The elements were edited parts of actual routines the gymnasts performed. The judges evaluated the performance of each as perfect or with a form error.

Test phase: The judges watched and evaluated the same gymnasts performing elements that were:

1. the same way as in the study phase;
2. a different way from in the study phase, i.e., with an error if perfect in study phase, or vice versa;
3. a new element, which was not in the study phase.

Results of each study:

- *Ste-Marie and Lee (1991)* showed the following order of judgment accuracy percentages for the three test-phase conditions:

  Highest judging accuracy: When the elements seen in the test phase were the same as those in the study phase
  Next highest judging accuracy: When the elements seen in the test phase were new
  Lowest judging accuracy: When the elements seen in the test phase were performed in a different way than they were in the study phase

This order of test accuracy demonstrates that observing and evaluating the performance of previously seen elements biased the judges' evaluations when the elements were performed differently from the previous observation. This bias is seen in the results that show lower judgment accuracy for elements the judges had seen previously, but that were performed differently, than for elements they had not seen previously. Interestingly, the bias occurred even though the judges were not consciously aware that they had seen the elements they evaluated in the same/different test conditions performed in the study phase.

- *Ste-Marie and Valiquette (1996)* showed the same order of accuracy as the Ste-Marie and Lee study when the test phase occurred immediately, one day, or one week after the study phases. These results indicate that the bias effects of previous observations persisted for at least one week.
- *Ste-Marie, Valiquette, and Taylor (2001)* showed the same order of test accuracy as the previous two studies when the study phase involved judging the performance of each element, naming the element performed, or naming the apparatus involved. These results indicate that the test accuracy results in the previous studies were due to watching the gymnasts perform during the study phase and not to the judges being involved in evaluating the performance of each element.

These studies provide excellent demonstrations of the influence of proactive interference on human memory, especially when the previous experiences involve characteristics that are similar to those involved in the test situation.

does during warm-up sessions (Ste-Marie & Lee, 1991; Ste-Marie & Valiquette, 1996; Ste-Marie, Valiquette, & Taylor, 2001).

Proactive interference in long-term memory. For movement information in long-term memory, the role of proactive interfering activities is not well known although the concept of negative transfer of learning, which will be discussed in chapter 13, is relevant to our understanding of proactive interference in long-term memory (see Koedijker, Oudejans, & Beek, 2010). An important feature of proactive interference in long-term memory is that we can quite readily overcome its effects by

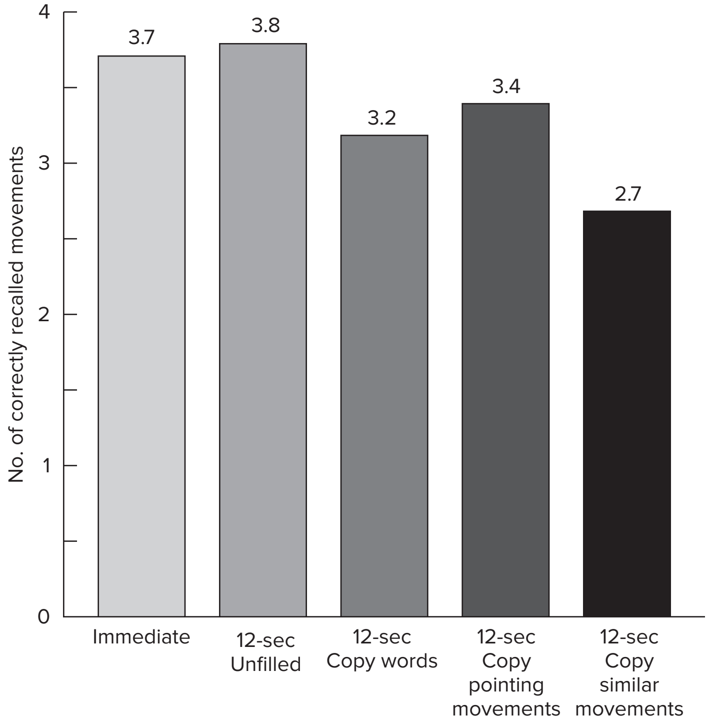

FIGURE 10.3 Free recall results of the experiment by Smyth and Pendleton showing the retroactive interference effects of performance of similar movements to those that had to be remembered. *Source:* From Smyth, M. M., & Pendleton, L. R. (1990). Space and movement in working memory. *Quarterly Journal of Experimental Psychology, 42A,* 291–304.

actively rehearsing the information. For motor skills, rehearsal occurs as we practice. This means that when we actively practice a skill, we strengthen its representation in memory and thus notice few, if any, effects of proactive interference (see Panzer & Shea, 2008; Panzer, Wilde, & Shea, 2006).

Retroactive Interference

If an interfering activity occurs after we perform a movement we need to remember (i.e., *during* the retention interval) and results in poorer retention performance than if no activity had occurred, the forgetting is said to be due to **retroactive interference**.

Retroactive interference in working memory. In working memory, it seems that rather than just any activity causing interference to the extent that retention performance is negatively affected, the *degree of similarity* between the interfering activity and the movement that must be remembered is an important factor. For example, participants in experiments by Smyth and Pendleton (1990) were shown a sequence of four movements, such as a forward bend of the head, both arms raised to shoulder level in front of the body, a bend of the knees, and left leg raised to the side. Following a retention interval, they had to perform these movements, either in sequence (serial recall) or in any order (free recall).

The influence of five different retention interval time and activity conditions on recall performance can be seen in figure 10.3. As you can see, these results showed that only when the retention interval involved subjects in recalling movements that were similar to those they had to remember did recall performance significantly suffer from activity in the retention interval.

Another characteristic of retroactive interference effects in working memory is one that we discussed for proactive interference. That is, activity

retroactive interference a cause of forgetting because of activity occurring during the retention interval.

during the retention interval causes interference that *increases recall performance error only when there is a certain amount of activity*. As long as the amount of information stays within this limit, remembering is not affected. However, when that limit is exceeded, forgetting occurs, which results in recall performance error increase.

Thus, the available research evidence indicates that retroactive interference for remembering just-presented movements occurs in two specific circumstances. These are situations when the activity during the retention interval is similar to the movements that must be remembered and when this activity and the movements to be remembered exceed working memory or attention-capacity limits.

Retroactive interference and long-term memory. It appears that retention interval length and/or activity does not have the same forgetting effects for all types of motor skills stored in *long-term memory*. Research evidence indicates that *certain types of motor skills are remembered better over long periods than are other types.* Your own experiences may provide some support for this. You probably had very little trouble remembering how to ride a bicycle, even after not having been on one for several years. However, you probably did experience some difficulty in putting together the pieces of a puzzle that you had assembled quickly around the same time you learned to ride a bicycle.

The characteristic of skills that distinguishes these two situations relates to one of the classification systems discussed in chapter 1. That is, *continuous motor skills* are typically more resistant to long-term forgetting than are discrete skills, especially when the skill involves producing a series of discrete movements in what we referred to as a serial motor skill.

Several reasons have been suggested to explain why this retention difference occurs. One is the difference in the *size of the verbal component* of the two types of skills. Serial discrete skills have a large verbal component, whereas this is small for continuous skills. This characteristic is significant because the verbal component of skills seems to deteriorate over time more readily than motor components. Another reason is that continuous skills are *practiced more* than are discrete skills. This is evident if you consider what a "trial" is for these two types of skills. One trial for a discrete skill is usually one performance of the skill, whereas one trial for a continuous skill is several repetitions of the skill over a much longer period of time. Thus, fifty trials of a continuous skill yield many more practice repetitions of the skill than do fifty trials of a discrete skill.

LAB LINKS

Lab 10a in the Online Learning Center Lab Manual provides an opportunity for you to experience the influence of time and activity on the remembering of limb movements in working memory.

MOVEMENT CHARACTERISTICS RELATED TO MEMORY PERFORMANCE

Location and Distance Characteristics

Actions have many characteristics that we can store in memory. For example, we could store the spatial position or location of various points of a movement, such as the beginning and the end point of a golf swing. We could also store the distance of a movement, its velocity, its force, and/or the direction of a movement. Two of these, *location* and *distance,* have been extensively examined with regard to how easily they can be stored in and retrieved from memory.

Investigation of the issue was very popular in the 1970s and focused primarily on the short-term storage in working memory of spatial positioning movements of the arm. The initial research studies found that movement end-point location is remembered better than movement distance (e.g., Diewert, 1975; Hagman, 1978; Laabs, 1973). In other words, they were better at reproducing the final position of the arm than how far the arm had moved. This can be tested by varying the start position of a movement but keeping the end location constant versus varying the start position and the end location but keeping the distance constant. An important finding showed that when movement end-point location information is a relatively reliable recall cue, people will use a location-type strategy to recall the movement (Diewert & Roy, 1978). However, when location information is totally unreliable and only distance information will aid recall, people will use some nonkinesthetic strategy, such as counting, to help remember the distance of the criterion movement.

Another characteristic of remembering location information is that an arm movement end location is more easily remembered when it is within the person's own body space (e.g., Chieffi, Allport, & Woodfin, 1999; Larish & Stelmach, 1982). For limb-positioning movements, people typically associate the end location of a movement with a body part and use that as a cue to aid their recall performance. Other research, which will be considered later, suggests that people will also spontaneously associate the end location of limb positions with well-known objects, such as a clock face, to aid recall.

What does all this mean for teaching motor skills? One implication is that if limb positions are important for successful performance of the skill, the instructor can emphasize these positions in ways that will facilitate learning the skill. For example, if you are teaching a beginner a golf swing, the important phases of the swing that he or she should concentrate on are critical location points in the swing. The keys could be the beginning point of the backswing or the location point of the top of the backswing. Or if a therapist or athletic trainer is working with a patient who needs to work on flexing or extending his or her knee, emphasizing the position of the lower leg can help the patient remember where the last movement was or to establish a goal for future flexion attempts. If a dancer or Pilates student is having difficulty remembering where her arm should be during a particular movement sequence, a body-part cue about the location of the arm can help her remember the position more effectively.

A note of caution is important here. Instructors of motor skills should not direct people to visually look to the location where the limb should move. Research has consistently shown that visually remembered locations for limb movements will be different from those remembered kinesthetically (see Simmering, Peterson, Darling, & Spencer, 2008, for a review of this research). This means that rather than enhancing the remembering of limb movement positions, the addition of visual information negatively influences how the positions are remembered.

The Meaningfulness of the Movement

Another characteristic that influences remembering movements is the *meaningfulness* of the movement. A movement or sequence of movements can be considered meaningful to an individual if that person can readily relate the movement to something he or she knows. For example, a movement that forms the shape of a triangle is considered more meaningful than one that makes an unfamiliar, abstract pattern. Or, if a movement is similar to one the person can do, then the new movement being learned takes on increased meaningfulness to the person.

The results of an experiment by Laugier and Cadopi (1996) illustrate the influence movement meaningfulness has on remembering movements. Adult novice dancers watched a video of a skilled dancer perform a four-element sequence of dance movements, each of which involved two to four head, body, and/or limb movements. One sequence, which the researchers labeled as a "concrete" sequence, was a sequence commonly performed in dance. Another sequence, labeled as an "abstract" sequence, involved elements that did not belong to any particular style of dance. After fifteen viewings of the dancer performing the sequences, the participants performed the sequence one time. Analysis of the participants' performance indicated that the observation of the concrete sequence led to better form and quality than the observation of the abstract sequence (see figure 10.4). Interviews of the participants indicated that the concrete sequence had a higher degree of meaningfulness to them, which helped them remember the sequence when they performed it.

STRATEGIES THAT ENHANCE MEMORY PERFORMANCE

There are several different strategies people can use to help them remember important movement characteristics of a skill, which in turn facilitate learning the skill. Note that some of these strategies

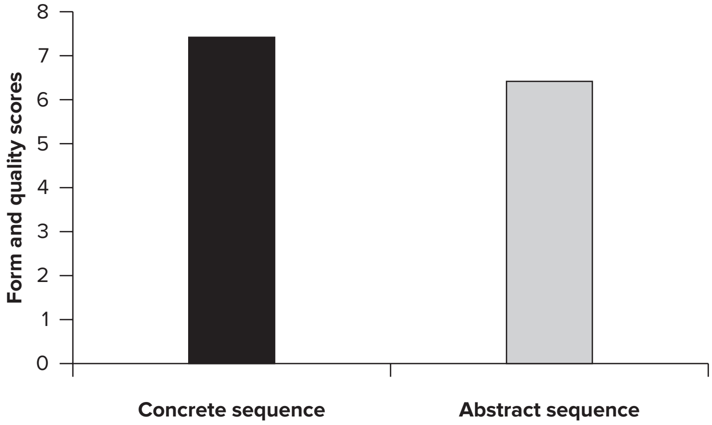

FIGURE 10.4 Results from the experiment by Laugier and Cadopi showing the influence of movement meaningfulness on remembering a four-element dance sequence. Scores reflect form and quality measures of novice dancers' one-time performance of the sequence after fifteen viewings of a skilled dancer performing the sequence. *Source:* Modified figure 2, p. 98, in Laugier, C., & Cadopi, M. (1996). Representational guidance of dance performance in adult novices: Effect of concrete vs. abstract movement. *International Journal of Sport Psychology, 27,* 91–108.

take advantage of the movement characteristics we just discussed that are more easily remembered than others. We will consider three general strategies that research evidence has shown to influence how well a movement is remembered.

Increasing a Movement's Meaningfulness

When people first practice a new skill, it is very likely that the skill will require that they coordinate their body and limbs in a new way. This characteristic makes it also likely that the new coordination pattern of movements will be more abstract than it is concrete. That is, the skill typically has little inherent "meaningfulness" to the learner in terms of spatial and temporal characteristics of the limb coordination needed to perform the skill. As you saw earlier in this discussion, movements that are higher in their meaningfulness will be remembered better than those low in meaningfulness. The instructor can take advantage of this characteristic by presenting to the learner a strategy that will increase the meaningfulness of the movements required to perform the skill. Two strategies are especially effective: visual imagery and verbal labels.

The use of *visual metaphoric imagery* as a memory strategy involves developing in your mind a picture of what a movement is like. As an instructor, it is best to use a metaphor for an image of something that is very familiar to the learner. For example, rather than provide the complex instructions for how to coordinate the arm movements to perform a sidestroke in swimming, the instructor can provide the learners with a useful metaphoric image to use while practicing the stroke. One such image is of themselves picking an apple from a tree with one hand, bringing the apple down, and putting the apple in a basket. In a rehabilitation context, physical therapists often teach the squat movement by having the patient visualize themselves sitting down on a toilet seat rather than describing each of the joint motions involved in the movement. Also, research by Nordin and Cumming (2005, 2007) has shown the beneficial use of metaphoric imagery by dancers to help them perform and remember how to perform complex dance skills. (The use of imagery as an instructional strategy will be discussed in more detail in chapter 19.)

Another effective strategy that increases the meaningfulness of a movement is to attach a meaningful *verbal label* to the movement. One of the earliest demonstrations of the beneficial influence of attaching verbal labels to movements was by John Shea (1977), who had participants move a lever to a stop on a semicircular arm-positioning apparatus. When they arrived at the criterion location, those in one group were provided with a number that corresponded to the clockface location of the criterion location; another group received an irrelevant verbal label such as a nonsensical three-letter syllable; another group received no verbal label about the criterion location. Results, as seen in figure 10.5, indicated that the group given a clockface label

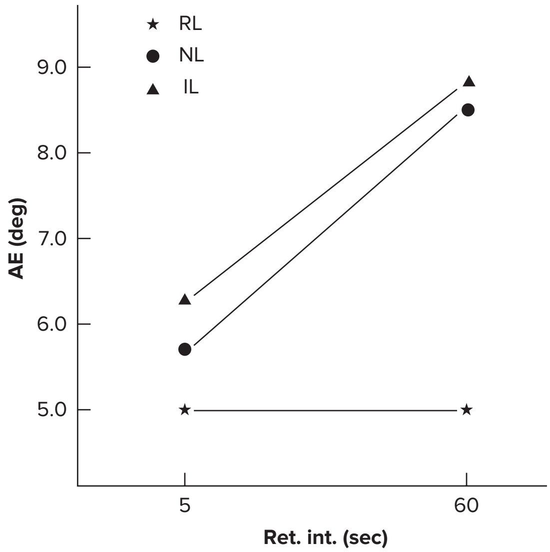

FIGURE 10.5 Mean absolute error computed across positions for the 5-sec and 60-sec retention intervals (ret. int.) in Experiment 1 by Shea. (RL = relevant label, NL = no label, IL = irrelevant label.) *Source:* From Shea, J. B. (1977). Effects of labeling on motor short-term memory. *Journal of Experimental Psychology: Human Learning and Memory, 3,* 92–99.

showed no increase in error over a 60 sec unfilled retention interval, whereas the other two groups showed a large increase in recall error. In a related experiment, Winther and Thomas (1981) showed that when useful verbal labels are attached to positioning movements, retention performance of young children (age seven) can become equivalent to that of adults.

There are at least four reasons why the use of visual metaphoric imagery and verbal labels aid the learning of complex motor skills. First, they reduce the complexity of the verbal instructions that would be needed to describe all the movements involved in performing the skill and their relationships to each other. This, in turn, reduces the demands on working memory. Second, they help change an abstract, complex array of movements to a more concrete, meaningful set of movements that is easier to remember. Third, they direct the performer's attention focus to the outcome of the movements rather than to the movements themselves, which, as we discussed in chapter 9, enhances the performance of skills. And fourth, they speed up the movement planning process by facilitating the retrieval of the appropriate memory representation of the action (Johnson, 1998).

The Intention to Remember

In all the memory experiments considered so far, participants have always known in advance that the movements they were presented or had to practice would be later subject to a recall test. But suppose they were not given this information in advance? Suppose they were told that the goal of the experiment was to see how well they could move their arms to a specified location. If an unexpected recall test was given later, how well would they recall the movements made earlier?

Intentional and incidental memory. The two situations just described are known in the memory research literature as *intentional* and *incidental* memory situations, respectively. In addition to investigating the influence of intention to remember as an effective remembering strategy, the comparison of these two situations provides insight into the encoding of movement information processes. That is, do we store only information to which we give conscious attention, as in the case of the intentional memory situation, or do we store more information, as would be shown by good memory performance, in the incidental memory situation?

This question has received little research interest in the study of memory for movements. However, the research that has been done indicates that, in general, intention to remember leads to better remembering than no intention to remember. (See Crocker & Dickinson, 1984, for a review of this research; and Badets & Blandin, 2012 and Badets, Blandin, Bouquet, & Shea, 2006, for more recent examples.) Yet retention test performance in the incidental situation is typically better than if no previous experience with the test movements had occurred. In fact, some reports show incidental memory test performance to be as good as it was for the intentional situation.

The investigation of intentional and incidental memory strategies is an important one to increase our understanding of memory processes related to encoding and storing information. Research indicates that we encode and store much more information than we are consciously aware of (see, for example, Perruchet, Chambaron, & Fervel-Chapus, 2003).

One implication that the intentional and incidental memory research provides for instructional situations is that memory performance and skill learning can be enhanced by telling students when they begin to practice a skill that they will be tested on the skill later. The effect of this advance knowledge about a test is that students will undoubtedly increase the amount of effort given in practice, a characteristic that you will repeatedly see in this text as beneficial for memory and learning. Also, when there are specific characteristics of a skill performance situation that must be remembered for a later test, a better test performance will result from telling people what these characteristics are.

Subjective Organization

A strategy frequently used by learners for large amounts of information is grouping or organizing the information into units. This strategy, which is known as *subjective organization,* involves the organizing of information that must be remembered in a way that is meaningful to the individual. Other terms that researchers have used to describe this strategy are *chunking, clustering,* and *grouping,* among others. An example of implementing this strategy is commonly seen when people need to learn a long monologue for a play, or a list of terms for a test. They often will organize the monologue or list by dividing it into shorter, more manageable chunks to begin memorizing the information. You would likely use a similar strategy if you had to play from memory a long piece of music on an instrument, or had to learn a dance or gymnastics routine. In each of these situations, continued practice typically leads to increasing the size of the chunks.

Although the role of subjective organization in motor skill learning has not been the subject of a large amount of research, there is evidence indicating that when given the opportunity to subjectively organize a sequence of movements, some people will spontaneously create an organized structure. And this subjectively determined organizational structure imposed on the sequence benefits recall performance (e.g., Magill & Lee, 1987). In addition, it is interesting to note that memory performance deficits often seen following a stroke (i.e., cerebrovascular accident) have been found to be due in part to a lack of ability to implement effective organizational strategies (e.g., Lange, Waked, Kirshblum, & DeLuca, 2000). Similarly, people with Parkinson's disease have been shown to have problems with implementing a subjective organization strategy without external guidance (Berger et al., 1999).

Novices' and experts' use of subjective organization. One way to apply the benefit of subjective organization to motor skill learning situations is to compare how novices and experts approach the learning of a complex skill. The novice tends to consider complex motor skills as comprising many parts. As the beginner develops his or her ability to execute the skill, the number of components of the skill seems to decrease. This does not mean the structure of the skill itself has changed. Rather, the learner's view of the skill has changed. A good example is a dance or gymnastic floor exercise routine, where each of the routines is made up of many individual parts. To the beginner, a dance routine is thought of step by step and movement by movement. Beginning gymnasts think of a floor exercise as so many individual stunts. As they practice, their approach to the skills changes. They begin to organize the routines into units or groups of movements. Three or four component parts are now considered as one. The result will be performing the entire routine with the requisite timing, rhythm, and coordination. With that result, moreover, will be the added effect of developing a more efficient means of storing the complex routine in memory.

Skilled performers organize information to such an extent that it appears they have an increased working memory capacity; this led Ericsson and Kintsch (1995) to propose the long-term working memory described earlier in this discussion. A good example of this type of subjective organization can be seen in the experiment with "novice" and "expert" eleven-year-old dancers by Starkes et al. (1987), which was mentioned earlier in the

A CLOSER LOOK

Active and Passive Limb Movements: Evidence for the Application of the Encoding Specificity Principle to Motor Skills

An excellent example of research evidence supporting the application of the encoding specificity principle to the remembering of movements is an experiment done many years ago by Lee and Hirota (1980).

- **Apparatus.** An arm-positioning apparatus on a table facing the participant.
- **Task and experimental conditions.** On some trials, blindfolded participants actively moved the handle of the apparatus along the trackway to a criterion arm position that was specified by a physical block. On other trials, they were passively moved by the experimenter to a criterion arm position. For the recall test on each trial, participants were told to actively move to the arm position just experienced or were passively moved by the experimenter until the participant told the experimenter to stop. This procedure continued until all participants had actively and passively experienced the presentation of each criterion arm position and had performed recall tests in either the same way they had experienced the presentation of the criterion position or the opposite way.
- **Encoding specificity principle predictions.**
  - ► Active movements to the criterion arm movements should be recalled better when the movements are actively recalled than passively recalled.
  - ► Passive movements to the criterion arm movements should be recalled better when the movements are passively recalled than when they are actively recalled.
- **Results.** As you can see in figure 10.6 below, the results supported the encoding specificity principle. When the movement during the recall test was performed in the same way as it was during the presentation of the criterion arm position (i.e., active–active, passive–passive), recall performance was more accurate than when the recall test was performed differently from the way it was during the presentation of the criterion arm position (i.e., active–passive, passive–active).
  - ► Note that there was no advantage to recalling active rather than passive movements. The difference in recall accuracy is more related to the relationship between the presentation and recall conditions.

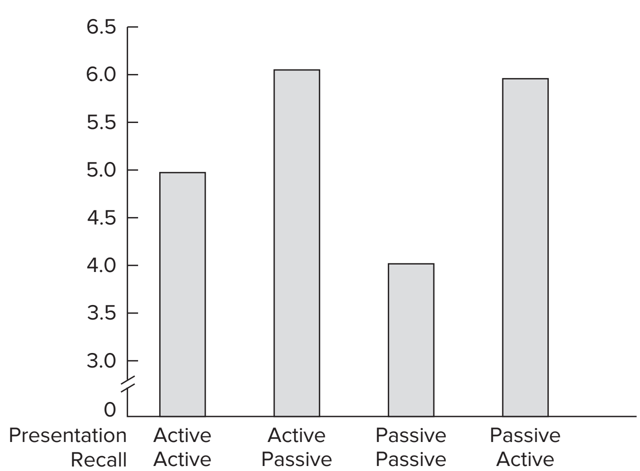

FIGURE 10.6 Results of the experiment by Lee and Hirota showing absolute error for recalling arm-position movements presented as either active or passive and recalled in either the same or opposite conditions. *Source:* From data in Lee, T. D., & Hirota, T. T. (1980). Encoding specificity principle in motor short-term memory. *Journal of Motor Behavior, 12,* 63–67.

LAB LINKS

Lab 10b in the Online Learning Center Lab Manual provides an opportunity for you to experience practice and test conditions that demonstrate the effects of the encoding specificity principle on remembering movements.

discussion of working memory capacity. When these dancers were presented sequences of eight elements that were organized as in a ballet routine, the expert dancers recalled the routine almost perfectly, whereas the novices recalled about half of the sequence correctly. However, when the same number of elements was presented in an unstructured sequence, there was no difference between the skilled and novice dancers in terms of the number of elements they correctly recalled. This result indicates that the organizational structure of the sequence of dance movements was an important factor in the experts' recall performance. In an interesting anecdote, the researchers reported observing an adult principal national-level ballet dancer being able to perform a sequence of ninety-six steps after having seen the sequence demonstrated one time. Thus, organization was apparently a strategy used to reduce the working memory load of this sequence and to increase the memorability of the sequence.

Similar organization effects were reported by Millslagle (2002) for experienced basketball players. Both male and female players were shown slides of structured and unstructured plays that could occur in game situations. On a recognition test given after the players viewed the slides, they more accurately remembered having seen slides that included the structured plays. Interestingly, when results were compared for the players who were guards, forwards, and centers, the guards' recognition accuracy was higher than it was for the forwards and centers. Because guards have more experience determining and implementing plays than the other two positions, the results of this experiment further emphasize the influence of expertise on the organizational structure of the information we store in memory.

PRACTICE-TEST CONTEXT EFFECTS

An important influence on the retention of motor skills is the relationship between the context of practice and the context at the time of the test. The context of a movement relates to both the environmental conditions in which the movement is performed and characteristics related to the person performing the movement. For example, if a memory experiment is performed in a laboratory, the environmental context includes such things as the room in which the experiment is done, the experimenter, the time of day, the noise the participant can hear, the lighting, and so on. Personal context involves such things as the mood of the individual, the limb used to make the movement, the sitting or standing position of the subject, and the sensory feedback sources that are available to the subject. As you will see in this section, differences in these conditions during the time the movement to be remembered or learned is presented or practiced and during the time the movement must be recalled can influence the success of the recall performance.

The Encoding Specificity Principle

An important point to consider regarding the influence of movement context on remembering or learning a motor skill is the relationship between the practice and test contexts. In some situations, especially for closed skills, the test goal is essentially the same as the practice goal. That is, to shoot a free throw, you must stand in essentially the same place and shoot the ball through a hoop that is the same distance from you as it was when you practiced it. In such closed-skill situations, the **encoding specificity principle** applies.

The encoding specificity principle was introduced by Tulving and Thomson (1973). According to this principle, the more the test context resembles the practice context, the better the retention performance will be. Evidence that this principle applies to motor skills has come primarily from laboratory-based experiments (e.g., Lee & Hirota, 1980; Magill & Lee, 1987). However, as you will see in more detail in chapter 13 in the discussion of the concept of the transfer of learning, ample evidence exists to have confidence in generalizing this principle to the learning and performance of motor skills.

The encoding specificity principle is based on research findings that indicate that *the memory representation for an action has stored with it important sensory and motor feedback information that is specific to the context conditions in which the action was practiced.* Thus, the more the test conditions match the practice conditions, the more accurate the test performance will be expected to be.

The practical implications of the encoding specificity principle seem especially relevant to learning closed skills. In a closed skill, the test context is typically stable and predictable. Because of this, practice conditions can be established that will closely mimic the test conditions. In these cases, then, the more similar the practice setting is to the test setting, the higher the probability of successful performance during the test. Consider, for example, practice for shooting free throws in a basketball game. Free throws are always one, two, or one-and-one situations. According to the encoding specificity principle, it is essential that players have practice experiences in which these gamelike conditions prevail. This does not say that this is the only way that free throws can be practiced. However, if game performance is the test of interest, it is essential that gamelike practice be provided.

Consider also a physical therapy example where a knee joint replacement patient is working on knee joint flexion and extension. Based on the encoding specificity principle, because test conditions involve active limb movement, practice conditions should emphasize active rather than passive limb movement. Similar practice-test relationships can be established for a variety of skill practice situations.

encoding specificity principle a memory principle that indicates the close relationship between encoding and retrieval memory processes; it states that memory test performance is directly related to the amount of similarity between the practice and the test contexts; i.e., the more similarity, the better the test performance will be.

SUMMARY

- Memory is best viewed as consisting of two functional component systems: working memory and long-term memory, with each having three subsystems.
- Working memory:
  - Consists of three subsystems:
    - phonological loop
    - visuospatial sketchpad
    - central executive
  - Serves two functions:
    - short-term storage system for information recently presented or retrieved from long-term memory
    - temporary interactive workspace for manipulating information
  - Has a limited capacity for information storage and the information remains for a short amount of time
- Long-term memory:
  - Consists of three subsystems:
    - Procedural memory
    - Semantic memory
    - Episodic memory
  - Stores the different types of knowledge in each subsystem on a more permanent basis
  - Seems to have no limits in terms of storage capacity
- *Forgetting* is a term used to describe the loss of memory or the inability to retrieve information from memory. Forgetting is usually measured by determining the amount of information that a person can recall or recognize following a retention interval.
- Both time and activity influence forgetting in both working memory and long-term memory. The causes of forgetting associated with these factors are referred to as trace decay, which means the memory representation deteriorates

over time, and interference, which can occur before (proactive interference) or after (retroactive interference) the presentation of the movement to be remembered.

- Movement-related characteristics that influence the remembering of a movement are the movement distance, movement end location, and the meaningfulness of the movement.
- Strategies that increase how well movements are remembered include the use of visual imagery and verbal labels; the subjective organization of a complex sequence of movements into meaningful units; and the intention to remember.
- The relationship between the practice and test context characteristics influences the remembering of movements according to the encoding specificity principle, which states that increasing the similarity between these context characteristics increases performance on a memory test.

POINTS FOR THE PRACTITIONER

- After giving instructions or a demonstration about how to perform a skill, keep the amount of time until people can physically practice the skill as short and free of other activity as possible.
- Do not describe or demonstrate "what not to do" before or after giving instructions or a demonstration about how to do a skill. If information about "what not to do" is needed, present the information after the people have had opportunities to practice the skill several times.
- If people ask questions about how to perform the skill after you give instructions or a demonstration, repeat the instructions or demonstration before allowing the people to begin physically practicing the skill.
- Instructions that provide specific movement endpoint location information in a metaphoric image or verbal label form, such as analog clockface locations, when appropriate for the movement being learned, will facilitate learning the skill.
- Whenever possible, provide visual metaphoric images and meaningful verbal labels to facilitate skill learning; either is preferable to movement-specific verbal instructions.
- To facilitate the learning of sequential skills, first demonstrate the entire sequence rather than the individual parts to help learners gain a sense of how the parts in the sequence relate to each other spatially and temporally.
- When active movement function is the desired outcome of instruction, active limb movement leads to better learning than passive limb movement.
- To enhance retention test performance, develop practice conditions that are as similar as possible to the test conditions.

RELATED READINGS

Awh, E., Jonides, J., Smith, E. E., Buxton, R. B., Frank, L. R., Love, T., . . . Gmeindl, L. (1999). Rehearsal in spatial working memory: Evidence from neuroimaging. *Psychological Science, 10,* 433–437.

Badets, A., & Osiurak, F. (2015). A goal-based mechanism for delayed motor intention: Considerations from motor skills, tool use and action memory. *Psychological Research, 79,* 345–360.

Baumann, O., Crawshaw, E., & McFadyen, J. (2018). Survival of the fittest: Increased stimulus competition during encoding results in fewer but more robust memory traces. *Frontiers in Psychology, 10*(21). doi: 10.3389/fpsyg.2019.00021

de Fockert, J. W., Rees, G., Frith, C. D., & Lavie, N. (2001). The role of working memory in visual selective attention. *Science, 291,* 1803–1806.

Ezzyat, Y., & Davachi, L. (2011). What constitutes an episode in episodic memory? *Psychological Science, 22*(2), 243–252.

Gong, Y., Ericsson, K. A., & Moxley, J. H. (2015). Recall of briefly presented chess positions and its relation to chess skill. *PLoS ONE, 10*(3): e0118756. doi:10.1371/journal.pone.0118756

Hancock, D. J., & Ste-Marie, D. M. (2014). Describing strategies used by elite, intermediate, and novice ice hockey referees. *Research Quarterly for Exercise and Sport, 85*, 351–364.

Jonides, J., Lacey, S. C., & Nee, D. E. (2005). Processes of working memory in mind and brain. *Current Directions in Psychological Science, 14,* 2–5.

Kantak, S.S., Sullivan, K. J., Fisher, B. E., Knowlton, B. J., & Winstein, C. J. (2010). Neural substrates of motor memory consolidation depend on practice structure. *Nature Neuroscience, 13*(8), 923–925.

Kimbrough, S. K., Wright, D. L., & Shea, C. H. (2001). Reducing the saliency of intentional stimuli results in greater contextual-dependent performance. *Memory, 9,* 133–143.

Labban, J. D., & Etnier, J. L. (2018). The effect of acute exercise on encoding and consolidation of long-term memory. *Journal of Sport and Exercise Psychology, 40,* 336–342.

Lawrence, B. M., Myerson, J., & Abrams, R. A. (2004). Interference with spatial working memory: An eye movement is more than a shift of attention. *Psychonomic Bulletin & Review, 11,* 488–494.

Maxwell, J. P., Masters, R. S. W., & Eves, F. F. (2003). The role of working memory in motor learning and performance. *Consciousness and Cognition, 12,* 376–402.

McCullick, B., Schempp, P., Hsu, S. H., Jung, J. H., Vickers, B., & Schuknecht, G. (2006). An analysis of the working memories of expert sport instructors. *Journal of Teaching in Physical Education, 25,* 149–165.

McIsaac, H. K., & Eich, E. (2002). Vantage point in episodic memory. *Psychonomic Bulletin & Review, 9,* 146–150.

Oliveira, F. T. P., & Ivry, R. B. (2008). The representation of action: Insights from bimanual coordination. *Current Directions in Psychological Science, 17*(2), 130–135.

Palmer, C. (2005). Sequence memory in music performance. *Current Directions in Psychological Science, 14,* 247–250.

Sakai, K., Kitaguchi, K., & Hikosaka, O. (2003). Chunking during human visuomotor sequence learning. *Experimental Brain Research, 152,* 229–242.

Sheeringa, R., Petersson, K. M., Oostenveld, R., Norris, D. G., Hagoort, P., & Bastiaansen, M. C. M. (2009). Trial by trial coupling between EEG and BOLD identifies networks related to alpha and theta EEG power increases during working memory maintenance. *NeuroImage, 44,* 1224–1238.

Silva, M. B., & Soares, A. B. (2018). Reconsolidation of human motor memory: From boundary conditions to behavioral interventions–How far are we from clinical applications. *Behavioral Brain Research, 353,* 83–90.

Sohn, Y. W., & Doane, S. M. (2003). Roles of working memory capacity and long-term working memory skill in complex task performance. *Memory & Cognition, 31,* 458–466.

Storm, B. C. (2011). The benefit of forgetting in thinking and remembering. *Current Directions in Psychological Science, 20*(5), 291–305.

Verneau, M., van der Kamp, J., Savelsbergh, G. J. P., & de Looze, M. P. (2015). Proactive and retroactive transfer of middle age adults in a sequential motor learning task. *Acta Psychologica, 156*, 57–63.

STUDY QUESTIONS

1. Discuss how working memory and long-term memory differ in terms of the duration and capacity of information in each.
2. Describe the functions of each of the subsystems for working memory and long-term memory.
3. Describe the meaning of the terms *declarative* and *procedural* knowledge. Give a motor skill example of each.
4. Discuss the primary causes of forgetting in working memory and in long-term memory.
5. Discuss two effective strategies a person can use to help him or her remember a movement or sequence of movements that he or she must perform. Give an example of the use of each strategy in a motor skill performance situation.
6. What is the *encoding specificity principle,* and how does it relate to the performance of motor skills?

Specific Application Problem:
You are working in your chosen profession. Describe how you would develop practice conditions as similar as possible to the test conditions in which the people with whom you work want to achieve success.