CHAPTER 6

Memory and Learning

Simon Marcus/Corbis

"It's a poor sort of memory that only works backwards," said the Queen.

—**Lewis Carroll (1832–1898)**
Alice in Wonderland

KEY QUESTIONS

- What is memory?
- What different memory systems underlie the learning and performance of motor skills?
- How do beginners and experts differ in their use of memory?
- How does memory explain "choking" during the performance of motor skills?
- Why can you perform well-learned skills without remembering doing so—like driving a car for many miles?
- Why do people forget well-learned skills?
- How can skills be practiced in ways that they will be better remembered?

CHAPTER OVERVIEW

Learn new skills twice as fast and with half the effort through scientifically proven memory enhancement techniques. . . . Yes, you can develop a super memory that will give you that edge over all opponents. Learn to remember like the champions do, using. . . .

We need not complete the sentence identifying the product promoted in this advertisement. Advertisements like this one promise to help athletes and recreational enthusiasts develop super memories for their activities, ease the effort of learning, and make one a more highly skilled performer by unlocking the secrets of memory.

If this advertisement seems too good to be true, that is because it is. There are no shortcuts to developing the memories underlying skill learning. Just because there are no shortcuts, however, does not mean that there are not better, as well as worse, ways of working with memory. In fact, no one really needs to worry about developing a super memory—everyone already has one. Memory is one of the most amazing capabilities humans possess; it is, in fact, arguably the most amazing. The many billions of neural circuits that form your memories are already capable of super feats. Your memory is able to store and to calculate more information than the most powerful computer. The secret, if there is one, is not to develop additional memory capacities, but simply to learn to take advantage of those you already possess. In this chapter, we will learn how memory works and how, when learning new motor skills, we can best take advantage of the remarkable natural capacities inherent within memory.

In the previous chapter, we defined learning as a set of unobservable processes developed as a result of practice that must be inferred from relatively stable changes in performance observed over time. Those processes underlying learning are, to a large extent, functions of memory. As stated in the words of an old phrase, "Memory is learning that sticks." Jack Adams, one of the prominent founders of the academic study of motor learning, stated that learning and memory are "just different sides of the same coin" (Adams, 1976, p. 87). The study of memory is therefore essential to our understanding of how skills are acquired and how practitioners can design better practice experiences for learners. Understanding how to work with memory, rather than against it, is a hallmark of the knowledgeable and effective instructor of motor skills.

WHAT IS MEMORY?

memory: The processes enabling humans to retain information over time.

An obvious fact is that we learn from experience. Something about our experiences changes our capacity to perform practiced skills in the future. The mechanism responsible for this change, for learning, is called **memory**. Simply stated, memory is the persistence of information over time, the capacity to learn from our experiences.

BOX 6.1 Ten Myths about Memory

In his book *Your Memory: How It Works and How to Improve It*, Kennett Higbee, a researcher specializing in the factors underlying memory, cites the following 10 myths that people commonly hold concerning memory (2001):

Myth 1: Memory is a thing.
Myth 2: There is a secret to a good memory.
Myth 3: There is an easy way to memorize.
Myth 4: Some people are stuck with bad memories.
Myth 5: Some people are blessed with photographic memories.
Myth 6: Some people are too old/young to improve their memories.
Myth 7: Memory, like a muscle, benefits from exercise.
Myth 8: A trained memory never forgets.
Myth 9: Remembering too much can clutter your mind.
Myth 10: People only use 10 percent of their mental potential.

memory trace: A network of neuronal brain cells encoded to store a specific memory.

Whatever else memory might be, its basic physical structure is housed in the brain through networks of neurons (referred to as a **memory trace**). These neural nets, comprised of thousands and even hundreds of thousands of individual neurons, are joined through millions of synaptic connections forming vast highways of electrochemical patterns representing specific memories—how to ride a bicycle, a favorite poem, where one attended first grade, how to best defend against a switch in a soccer game.

In the not too recent past, it was believed that neural networks were static, fixed structures located in specific brain centers and immutable to change. Modern instruments for studying memory, like PET scanners that provide a close-up of which parts of the brain are active during the formation and later recall of memories, are painting an entirely new picture of how and where memories are formed in the human brain, however. It is now clear that there is no single center for a memory (Baddeley, Eysenck, and Anderson, 2009; Johnson, 2004; Kandel, 2006; and Ratey, 2001). Rather, a memory is compartmentalized into various brain regions—hippocampus, frontal lobes, motor cortex, and so on—from which it can later be retrieved and reassembled when needed. Memories are like puzzle pieces spread out across the brain, which we bring together as a whole only when we retrieve them.

The question naturally arising is whether a memory is located someplace or is a process that occurs only when the memory is retrieved. Endel Tulving, one of the best known memory researchers in the world, after a lifetime studying memory confessed that he did not know if memory was "a storage space, or the act and strategy of retrieval" (quoted in Ratey, 2001, p. 185). We might best think of memory as a coin, with one side being storage and the other side process. When we take the coin out to use, we can focus our attention on whichever side is most beneficial at the time for providing the answers we seek (see Box 6.2).

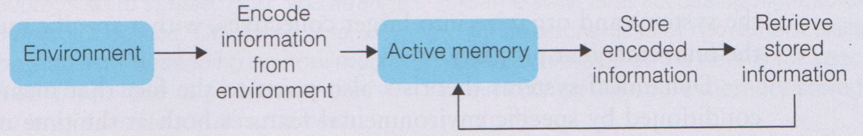
BOX 6.2 The Vocabulary of Memory

Any memory system, regardless of the system in question, requires three things—the capacity to encode, store, and retrieve information. These form the primary processes describing memory. Definitions for these terms are provided below:

encoding The processes involved in originally registering information from the environment into memory.

storage The capacity to retain encoded information in both active and nonactive forms until needed.

retrieval The ability to locate and recall information stored within memory systems.



Theoretical Perspectives on Memory

Although modern brain research is adding to our understanding of memory, theoretical consensus remains elusive. A theoretical gap exists between those theorists, on the one hand, who view new memory findings in ways supporting cognitive-based theories, and those on the other hand who interpret new evidence as supporting dynamical systems theories.

Cognitive-Based Theories of Memory

Cognitive-based theorists have focused attention on the brain structures responsible for storing individual memory components. They can rightly point to the fact that memory (at least in its pre-retrieved form) is located in specific brain regions on which specific neurological processes act. A widely accepted theory among cognitive-based scientists is that the individual components of memory, when retrieved, come together in convergence centers (Damasio, 1994; Ratey, 2001).

convergence center: A theory that memories are stored in parts across the brain and only brought together through retrieval processes near the sites where they were initially perceived.

In this view, when a memory is retrieved, its individual components are assembled near the sensory neurons where the events forming the memory were initially registered, with this specific location being called a *convergence center*.

The notion of convergence centers carries an even greater appeal for cognitive-based theories than merely the hierarchical location of control centers in the brain. Advocates of this approach posit that convergence centers are hierarchical. That is, convergence centers range from low-level centers for general memory features, to high-level centers for specific memory features. In theory, there could be (as a hypothetical illustration) a lower-level center for all striking skills, a somewhat higher-level center for striking skills using a tennis racquet, an even higher-level center for returning balls using a backhand striking movement, and finally a highest-level center for shot placement in a specific situation using a backhanded return. Instead of having to store many individual memory elements, such hierarchical arrangement makes both storage space and retrieval processes manageable. If this idea looks familiar, that is because it reflects the ideas underlying schema theory presented in Chapter 4 (see Box 6.3). Memory, in this view, is seen as a top-down, hierarchical arrangement in which higher brain centers, those associated with managing the organization and retrieval of memories, are the essential features underlying the control of actions.

Dynamical Systems Theories of Memory

Just as cognitive-based theorists find much to support their ideas in contemporary views of memory, dynamical systems theorists also find much to support their major theoretical positions. Certainly, the neural structures underlying memory fit the definition of complex, adapting systems. Most critical to these theorists is that newly developing views of memory appear to highlight processes of self-organization, adapting networks, and emergence. Inherent in the modern science of memory is the concept, which we have only briefly sketched, that neural networks adapt to their environments (through sensory inputs to the system) and organize into larger collectives, with a specific memory being the final emergent property.

Dynamical systems theorists also point to the fact that memory appears conditioned by specific environmental features both at the time of formation and later during recall, and by an individual's previous knowledge, perceptual capabilities, and psychological state. That is why two people can experience exactly the same event yet have very different memories of it. The point is, though, that many aspects of the original event ultimately encoded within memory must be taken into account. Neural processes alone are not sufficient to explain memory. Thus, memory is viewed as a bottom-up process in which many systems and subsystems interact and have equally important roles to play in memory and the learning of movement skills (see Box 6.4).

The Current Theoretical Landscape

We should not proceed before noting that most of the research directed toward the effects of memory on the learning of motor skills has been conducted from cognitive-based theoretical perspectives. Although dynamical systems theorists have focused considerable attention on how neural networks are formed and how they behave, they have to date focused less attention on memory and even less on memory for motor skills (an exception is the study of perception and memory from an ecological perspective). This lack of systems-based approaches is probably due more to the relative newness of dynamical systems theory compared to cognitive-based approaches and to the greater focus therefore paid to basic questions of theory rather than more applied areas such as learning theory. Most of the research studies reviewed

BOX 6.3 Memory of Motor Skills as Schema

According to schema theory, memories for movement skills are stored in hierarchical arrangements. The details for controlling skills in specific ways are embedded within larger, all-encompassing memories for entire classes of action (see Chapter 4). Memories for executing skills in specific ways are retrieved by first accessing a higher-order, generalized memory structure, from which lower-order details for executing the skill in specific ways can then be retrieved. An interesting experiment illustrating how schema theory works was reported in the cognitive domain of learning by Bransford and Johnson (1972).

In this experiment, subjects were asked to read the following passage, after which they were tested for their recall and understanding:

The procedure is quite simple. First, you arrange items into different groups. Of course, one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities that is the next step; otherwise, you are pretty well set. It is important not to overdo things. That is, it is better to do too few things at once than too many. In the short run this may not seem important but complications can easily arise.

Subjects read the passage either with or without reading a title beforehand. Those who read the passage without first reading its title remembered very few details and were unable to provide any meaningful context for the described procedures. Those who were first presented with the title of the passage displayed good recall of described procedures, and were able to place those procedures perfectly into their proper context. The title of the passage was "Washing Clothes." The schema for movement skills works in the same way. First accessing higher-order memory for an entire class of movement skills allows much easier retrieval of the details for specific actions, simplifying the entire memory storage and retrieval process.

in this chapter necessarily represent cognitive-based approaches, though their descriptive findings should prove acceptable to those representing either theoretical approach.

MEMORY SYSTEMS

If asked the seemingly odd question "How many different memory systems are there?" most people would probably reply that everyone has just one system for memory—the one he or she is consciously aware of and thinks with. Memory, however, is actually composed of two independent systems, one of which is then further made up of two subsystems, so that three distinct memory systems comprise human memory (Baddeley, 2004; Baddeley, Eysenck, and Anderson, 2009). These three memory systems include the declarative system, comprised of semantic and episodic subsystems, and the procedural system. We will examine each of these memory systems.

BOX 6.4 The Rhythms of Memory

In the view of dynamical systems theorists, memories emerge as the result of the self-organizing activities of networks of neurons within the brain. One result of self-organization of neuronal collectives is that all of the neurons within the network synchronize their activity so that rather than random firing patterns among many individual neurons, a single pattern of activity emerges. In 2001, Fell and colleagues (cited in Strogatz, 2003) offered the first experimental evidence for the synchronization of neurons as a prerequisite for memory.

In their study, Fell and associates asked subjects to memorize a list of words one at a time. Later, after engaging in distracting activities, subjects were tested on their recall of the list. During the original learning period as subjects were attempting to memorize the list of words, the researchers measured the firing patterns of neurons in two different areas of the brain known to be associated with memory—the hippocampus and rhinal cortex. (This was possible because subjects were epileptics who had electrodes implanted in these brain regions in preparation for neurosurgical procedures, which allowed for direct monitoring of neural activity during memorization.)

As would be expected, subjects remembered some words, but not others. What was amazing, though, was that when subjects were attempting to learn the word list, during their memorization activities, for some of the words the firing patterns of neurons in both brain regions would spontaneously shift into a perfectly synchronized pattern of firing, with rates of firing varying rhythmically, as in an orchestrated symphony of electrical impulses, between 30 and 50 cycles per second. While attempting to memorize other words, however, firing patterns remained random and displayed no degree of synchronization indicative of self-organization. What was truly amazing came when the researchers compared the words for which synchronous firing patterns were evident in both brain regions, to those words that were later remembered in the recall test. There was a perfect correlation. Those words that were remembered were the ones in which synchronized firing patterns occurred during learning. Subjects were unable to remember, however, those words for which random firing patterns only were observed. Although much more research is needed in this area, studies such as this one (there have been others since as well) offer strong evidence supporting the dynamical systems approach to the conceptualization of memory.

Declarative Memory System

declarative memory: A memory system specialized for holding and operating on information concerning objective facts and events.

Declarative memory is a system containing our memories concerning facts and events, both those of a personal nature as well as those about the world around us. Declarative knowledge is knowledge that we can "declare," that is, which we can articulate and tell others about. The declarative memory system contains the knowledge of which we are consciously aware; when we think about our memories, we are really thinking about declarative memories. Declarative memories are further divided into two subsystems called the semantic and episodic systems (note that some theorists consider these two systems as merely different aspects of declarative memory, whereas others view them as entirely distinct and separate systems) (Tulving, 1972).

Semantic Memory

semantic memory: A memory system specialized for holding and operating on information of a generalized factual nature.

Semantic memory includes generalized knowledge about the world: the capital of North Dakota, who wrote *The Iliad* and *The Odyssey*, the distance to the moon, how to tell time, the rules of baseball, and which club to use for a chip shot, for example. Semantic memory allows us to make sense of the world; it provides the knowledge necessary to organize, interpret, and give meaning to ongoing events. Semantic memory is also independent of the sequence and context in which information occurs; that is, semantic memories are stored independently from where and when they were originally acquired. You know that you should not cross a street on a red light, for example, but have probably long forgotten the specific time and place where you originally acquired this fact.

Episodic Memory

episodic memory: A memory system specialized for holding and operating on information of a personal nature and specifying the time and place that events occurred.

Episodic memory stores information concering specific events as related to an individual where and when you attended grammar school, your favorite movie, your least favorite food, a remembered smile from a friend, or knowledge that you left the TV on when leaving home this morning. Episodic memory is autobiographical. It is also context and sequence related; it tells us when and where events occurred and provides the basis for organizing events into a meaningful time frame (i.e., putting events in temporal order—which came first).

Procedural Memory System

For a considerable time, psychologists and others studying memory believed that only declarative memories—those that could be articulated—underlay all human behaviors, including skilled motor behaviors. This notion was shattered in the 1950s when scientific reports first appeared concerning a young amnesic patient anonymously referred to simply as H.M. (see Squire and Kandel, 2000, pp. 11–16). As a boy of 9, H.M. suffered head injuries in a bicycle accident that ultimately led to epilepsy. Over the years, H.M.'s condition grew worse, and by the time he was 27 in 1953, he was severely impaired. Because at that time epilepsy was believed centered in the hippocampus of the brain, doctors decided on radically experimental surgery to remove this structure. The surgery proved a success in alleviating H.M.'s epilepsy. Unfortunately, there were unforeseen consequences. From the time of his surgery, H.M. appeared no longer able to form new memories (at least ones of which he was conscious). He could retain information for a few minutes but then forgot what had just happened. His recall of events that had occurred prior to his surgery, even those from earliest childhood, remained intact throughout the rest of his life, however. Over a long life that followed, he believed, whenever asked about current events, that Dwight Eisenhower had just been elected president; the song currently topping the music charts was "How Much Is That Doggie in the Window?" and that the New York Yankees had recently beaten the Brooklyn Dodgers four games to two in the World Series. The events proceeding his surgery became his current reality for the remainder of his life.

What had not been realized prior to his surgery was that the hippocampus, which was removed from H.M., was critical to the formation of declarative memories, at that time the only type of memory believed to exist. But then one of the most remarkable experiments in memory research was conducted (Scoville and Milner, 1957). Based more on intuition than on either theory or evidence, a researcher by the name of Brenda Milner decided to test whether H.M. could learn new motor skills. The motor skill that Milner selected for her research was star-mirror tracing, a frequently used task among motor learning researchers. In this task, subjects are required to perform fine hand–arm movements by quickly guiding a stylus over a narrow line shaped in the pattern of a star while viewing their hand and the star pattern in a mirror reversing the normal image. The results of H.M.'s learning of this skill stunned memory experts. Not only did H.M. improve his skill level, he improved at a rate as great as that observed within the normal population. Even so, each time he was presented with the tracing task, H.M. believed that he was experiencing it for the first time.

At first, many researchers were prone to interpret these astonishing findings as evidence that motor skills must be stored in some special and separate memory system apart from other memories. It soon became apparent, however, that not only motor skills, but also the entire range of behaviors that could be classified as skills were also controlled by a memory system that had to be different from the one used to store declarative memories. What the story of H.M. revealed was not that a specialized memory system exists for motor skills, but that a separate memory system exists that underlies all skill learning. Because this system stored information relative to the procedures for accomplishing skills, regardless of the particular type of skill, it was called the **procedural memory** system.

procedural memory: A memory system specialized for holding and operating on information pertaining to the execution of skilled behaviors and functioning at a nonconscious level.

The procedural memory system is specialized to store information for skills; it contains memories underlying skills in all three domains of skilled behavior—cognitive, perceptual, and motor. Procedural knowledge deals with "how to" perform various skills, rather than "knowing about" the skills; it is a rule-based system containing the procedures allowing for the expression of skilled action. You use procedural memory for hundreds of activities every day—to tie your shoelaces, ride a bicycle, catch a ball, type a letter, play a musical instrument, dance, and drive a car. If you stop to think about each of these activities for a moment, it becomes obvious that more than the knowledge

HO/eyevine

Henry Gustav Molaison, known worldwide as H.M. to protect his privacy, died at the age of 82 in 2008. From the time he received experimental brain surgery at age 27 in 1953, he could form no new memories, although his memory for events occurring prior to his surgery remained unimpaired. His intellect and personality also remained unimpaired—he was persistently happy and optimistic, and he was always eager to talk with the many memory researchers who came to study his case. He became the most widely studied patient in the field of memory research, and it is estimated that more is known about memory today because of him than any other source.

of each is necessary in actually accomplishing it. You can read hundreds of books about typing and "know" everything there is to understand about how to type, for example, and still not be able to type. Even though you may have an extensive declarative memory about typing, the actual steps for controlling the arm and hand movements, as well as the perceptual abilities necessary in finding the correct letters on a keyboard, are not encoded into memory along with merely learning the "facts" about typing. Memories governing the perceptual and motor components of typing must also be established in order for the declarative facts about typing to be actualized in the real world. So, procedural memories govern the "doing" of skilled behaviors (see Figure 6.1).

In the examples of procedural skills in the paragraph above, you might have noticed another important feature of each activity. That is, you perform them, at least when well learned, with little or no conscious thought. This distinction in cognitive awareness between declarative (conscious awareness) and procedural (nonconscious awareness) systems can easily be illustrated when considering any action in which you are highly skilled. To return to our typing example, for instance, as I type this page I have no difficulty in striking the correct letter keys to form the desired words on the page. In fact, I have been typing for so many years (since freshman year in high school) that my fingers

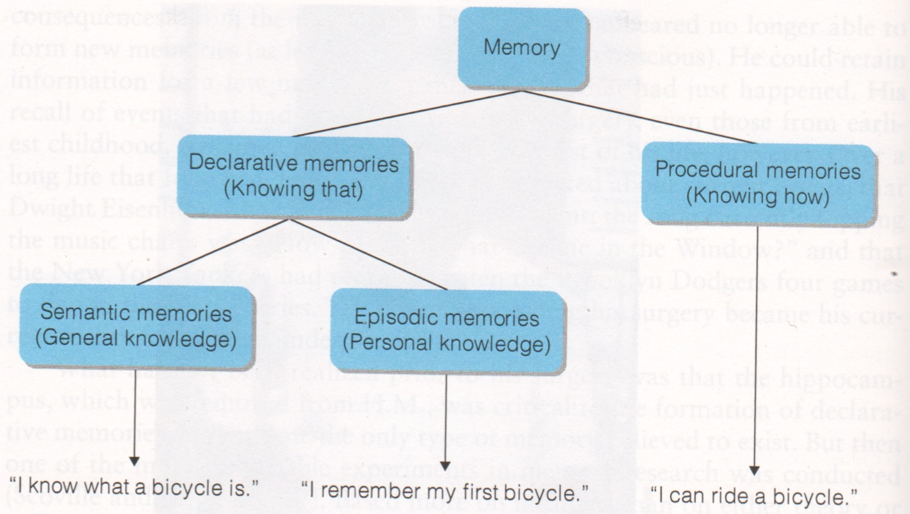


FIGURE 6.1 Memory Systems

Source: Created by author.

automatically go to the correct keys without "thinking" about how I do it-and without the need to look at the keyboard. That is, I have developed, over many years of typing, a rich procedural memory of rules for typing that underlies a fairly well-developed typing skill. I can type any letter needed to assemble the words I want on the page—as long as you do not ask me where the letter is on the keyboard or which finger (or even hand) I use to type it. If asked this question, I have to look on the keyboard and locate the respective letter key—I do not "know" where it is. What it means, in this case, to say, "I do not know where the letter is located," is really to say that I do not have access to my declarative memory for typing (the memory informing conscious awareness of where different keys are located). At some point in the past, when I was first learning to type, I obviously knew where the various letter keys were located on a standard keyboard. The information was in declarative memory but has long since been forgotten, and I can no longer retrieve it into conscious memory. Still, my procedural memory of typing—the one I use regularly and therefore frequently "refresh"—allows me to strike the correct keys accurately and to type even when I no longer remember "how" to type. The reader can no doubt think of many examples of skills contained in procedural memory that can be performed automatically and seemingly without thought, but if asked to elaborate upon the rules, one might have considerable difficulty articulating them.

automaticity: The capacity of individuals to access and operate on procedural memory without the need for conscious attentional resources when executing well-learned skills.

Procedural memory has an advantage when performing skills that is so obvious that it may easily be initially overlooked. Procedural control of skills is carried out without the need for conscious attention, a capacity referred to as **automaticity**. This means that our conscious awareness, which is limited in its capacity, can be directed toward other activities while still performing skills effectively. Think, for example, of a basketball player dribbling a ball downcourt during a game. If the player had to devote her limited attention to accomplishing the highly coordinated acts of running and dribbling, she would not have enough attentional resources remaining to think effectively about what to do in the game (i.e., whether to pass the ball to a teammate, how much time is remaining on the shot clock, what play to run, etc.). Procedural memory makes it possible for humans to carry out varied and highly complex skills while leaving cognitive resources available for other mental activities (planning ahead or carrying on a conversation, for instance), a capability sometimes called *dual tasking*.

Procedural knowledge does not appear to be stored directly into the procedural memory system, however, but is most frequently transferred from declarative memory (though there is still debate about this among experts). What, in effect, this means is that some degree of declarative knowledge must typically first be developed and is essential before procedural memory can be formed. You first have to learn the "facts" of the skill (i.e., the goals, rules, mechanics, what to pay attention to, etc.); that is, you first acquire some declarative knowledge of the skill. Early in learning a motor skill, for example, you "think" your way through performing the skill using the conscious facts you encode into declarative memory stores. Over time, this declarative knowledge fades and you begin to do more and more of the skill automatically, without "thinking" about it. This is an illustration that your knowledge of the procedures underlying the skill—the proceduralization of the skill—is being transferred from declarative memory to procedural memory. Over time, you may forget your original knowledge concerning how you perform a skill as declarative memory fades into a forgotten past, even though your capacity to perform continues to improve as procedural memories are used and reinforced (see Box 6.5 to test your ability to identify memory systems).

Novice and Expert Differences

The discovery of the procedural memory system answered many questions researchers had been asking about the acquisition of motor skills. Today, the

BOX 6.5 Can You Identify the Memory System?

Three distinct types of memories have been identified and are believed to comprise three separate memory systems—the declarative system made up of semantic and episodic subsystems, and the procedural system. See whether you can identify the system—semantic, episodic, or procedural—of which each of the following memories would be a part.

- Being able to dribble a basketball
- Knowing the rules for playing tennis
- Remembering the score of the last game of tennis you played
- Being an excellent skateboarder
- The first time you played a Wii game
- The date of Columbus's first voyage to the Americas
- Your favorite musical group
- How you spell your name
- Signing your name

distinction between these systems continues to provide for meaningful analyses in many areas of inquiry. One area that has come under particular scrutiny is the differences between novice (i.e., beginner) and expert performers. Both cognitive-based and dynamical systems theorists have found the distinctions between these systems of memory useful in understanding the differences between individuals based upon skill level. Below we consider two studies designed to highlight differences between beginning and experienced performers based upon considerations of how each makes use of memory. One study, investigating the differences between novice and experienced golfers, was conducted under cognitive-based assumptions concerning memory. The other, examining differences in sport wall climbers of different skill levels, was completed using dynamical systems assumptions.

The Causes of "Choking"—When Declarative Memory Harms Performance

To test the roles played by declarative and procedural memories in acquiring motor skills, Beilock and Carr (2001) conducted an experiment comparing golf putting performance between expert and novice performers, subjects who could be expected to be differentially relying on declarative and procedural memory in their execution of golfing skills. Participants in the experiment were college students who were grouped as either expert or novice golf performers. Expert putters included subjects who had participated in at least two years of high school varsity golf and held a PGA (Professional Golf Association) certification; the novice group was comprised of students with no golfing experience. The task for both groups was the same and included putting a golf ball on a carpeted indoor green to a target on the floor from locations of various distances and angles. Scores were computed by averaging the distance off target for all putts for each of the conditions.

Following the 30-putt practice condition, each subject from both groups was asked to produce a "generic knowledge protocol" of how the golf putt should correctly be performed. Specifically, subjects were asked to respond to the question: "Certain steps are involved in executing a golf putt. Please list as many steps that you can think of, in the right order, which are involved in a typical golf putt." Answers were compared to a list of steps in executing a correct golf putt derived from interviews with professional golf instructors and an analysis of "how to" books on putting. Subjects were scored based upon the length, detail, and correctness of their answers as compared to this master list.

As might be expected, expert golfers were significantly better than novices at generating correct lists of steps for putting; their answers were longer, more detailed, and considerably more accurate. This is an indication that experts had superiorly developed semantic memories of putting compared to the less experienced novices. This is, not surprisingly, what one would expect to find.

The findings became more interesting when subjects were asked to describe in as much detail as possible their episodic memories of their putting performances. Specifically, they were asked: "Pretend that your friend walked into the room. Describe the last putt you took, in enough detail so that your friend could duplicate the last putt you just took in detail, doing it just like you did." When asked this question, the novices produced longer, more detailed, and more accurate descriptions of their performance than did the experts. Contrary to what might have been expected, novice performers displayed better episodic memory of their practice attempts than did experts. Beilock and Carr hypothesized that the experts' reliance on well developed, but automatic and nonconscious, procedural memories of putting actually blocked their recall of the performance events as they unfolded. That is, during the actual execution of a putt, experts controlled their actions through procedural memory structures that effectively blocked access to episodic monitoring of events as they occurred. Simply stated, the experts were less aware of their actions than were the novices, even though they were performing much better.

Surely, however, if experts knew in advance that they would be asked to recall their specific experiences, they would be able to apply their superior semantic knowledge to pay closer attention to a skilled performance and therefore be more proficient at analyzing their performances than would less experienced performers. To test this notion, Beilock and Carr repeated the same procedures on a second set of practice trials, but this time subjects were told before their last putt that they would be asked to describe it in detail just as they had after the first post-test. Although experts did somewhat better on this second recalling of their episodic memories, they still did not do as well as the novice group of subjects (see Figure 6.2). Surprisingly, experts, whose performances were much superior to novices largely because of their richer encoding of the skill requirements for putting into a procedural memory form, had less access to their declarative episodic memory of the skill than did novices (though not to their semantic memories of the skill). Highly skilled performances, it would appear, are controlled through automated procedural


Bob Daemmrich/PhotoEdit

Overthinking when putting can block a skilled golfer's access to procedural memory, resulting in "choking" and degraded performance.

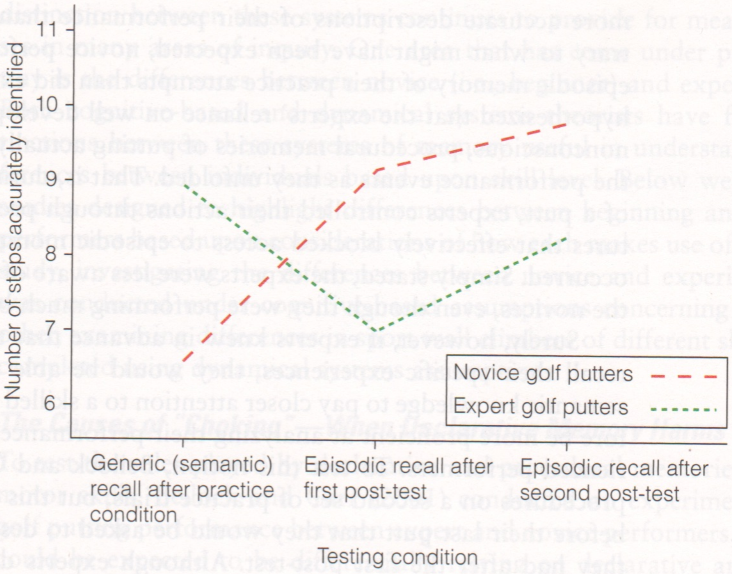


FIGURE 6.2 Results of Beilock and Carr Study

memory structures that operate outside of the scope of conscious attention and therefore remain substantially closed to explicit analysis and recall. Beilock and Carr called this phenomenon of experts' comparative impoverished episodic memories **expertise-induced amnesia.**

expert-induced amnesia: A term used to describe the tendency for highly skilled performers to exclude episodic monitoring during the execution of skills.

Based upon the findings of this research and several other supporting studies (e.g., Beilock et al., 2002; Beilock, Wierenga, and Carr, 2002; and Beilock et al., 2004), Beilock and Carr have argued that a primary cause of "choking" in athletic or other stressful situations in which highly skilled individuals perform (i.e., firefighters, police and military personnel, surgeons, heavy equipment operators, etc.) results when experts attempt to pay too much attention to their external environments (rather than too little, which has sometimes been argued as the cause of choking). That is, choking—performing worse than expected when under pressure—appears to be the result of attempts on the part of skilled performers to harness declarative memories in the execution of skills that have long since been encoded into procedural form. Accessing declarative memory structures during execution of these well-developed skills disrupts the normal functioning of procedural memories best operating in isolation from conscious semantic or episodic intervention, and which are capable of best guiding skilled action in automated and nonconscious fashion. These conclusions support a theory of choking called the *expert-monitoring hypothesis*, that paying too much attention to well-learned skills may prove detrimental to performance. Many current notions of high-level athletic performance also support this conclusion, such as the concepts of "flow" and "inner-game" theory (see, for example, Jackson and Csikszentmihalyi, 1999; and Kauss, 2000). An appreciation for the workings of memory, in this case, helps us to both understand and make practical instructional suggestions concerning a persistent, and still somewhat debated, aspect of highly skilled performances.

Attunement to Affordances

affordances: The properties of an object or of the environment that offer opportunities for action.

Before leaving our discussion of differences between beginning and experienced learners, we will consider an additional experiment, but this time, one from the perspective of dynamical systems theory. You may recall from Chapter 3 that dynamical systems theorists view memory as including the coupling of perceptual and action control systems, referred to as the perception of **affordances**. Memory means becoming more attuned to the possibilities available in the environment to accomplish skills effectively. Expert performers, in this view, are better able to perceive within the environment information maximizing their opportunities for successfully accomplishing the goals of a particular skill.

In a test of this theory of memory, researchers examined differences in memory use of expert and beginner sport wall climbers (Boschker, Bakker, and Michaels, 2002). Highly experienced wall climbers were compared to beginners with some experience, but who were still in the early stages of learning. Both groups were exposed to a climbing wall that they could study for several minutes. They were then asked to record on a model their recollections of the wall surface (hand- and footholds, overhangs, etc.). Beginners displayed a rich semantic memory of wall features, but those features they recalled were random structural features bearing no relationship to how they might actually climb the wall (that is, they afforded a low opportunity for climbing the wall successfully). Experienced climbers, on the other hand, did not recall nearly as much detail concerning the specific location of wall features, but they did recall available pathways for climbing the wall that would afford the best opportunities for achieving success. This is another example of how highly skilled performers appear to rely upon procedural memory to the exclusion of declarative memory structures, and indicated that such a prioritizing of memory resources provides many distinct advantages for highly skilled performers.

THE STAGES OF MEMORY

If individuals are to be aware of their environment and to respond effectively to it, three essential things must happen. Each of these three things in turn requires specialized functions of memory. First, as obvious as it seems, we must be aware of what is in the environment; more to the point, we must focus our limited attentional resources on the most critical and important aspects of our perceived environment. Once we focus on important environmental information, we must next decide what to do in response, as well as how to do it. Finally, if learning is to occur, we must be able to retain the lessons of past experiences for use in the future. These three functions are made possible through human memory. Because each of these three essential functions is accomplished by separate memory structures and processes, it is typical to consider memory as involving three separate stages. These stages are labeled

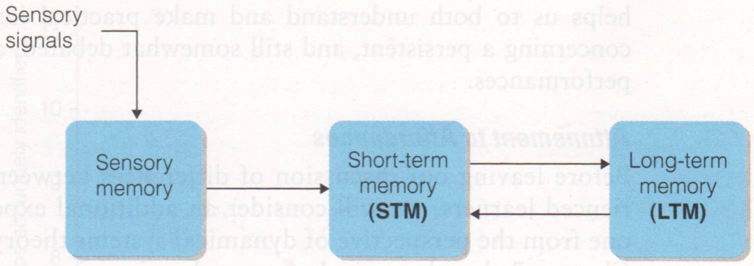


FIGURE 6.3 Stages of Memory
Source: Created by author.

sensory memory, short-term memory, and long-term memory (Figure 6.3). An early influential model of these stages was reported by Atkinson and Shiffrin (1968, 1971), so it is often referred to as the Atkinson and Shiffrin model of memory (for fuller and good discussions of this model, see Baddeley, 2004; Klatzky, 1980; and Smith, 1998).

Sensory Memory

sensory memory: A memory system specialized for encoding all incoming sensory signals and transferring relevant information to short-term memory for attention and possible action.

Sensory memory is the first stage in the process of memory. Information from the environment first enters memory through this stage. This stage of memory takes in virtually everything registered by the body's various sensory receptors and holds it for a brief period during which it can be organized, prioritized, and encoded in transferable form for transfer to following stages in the chain of memory formation. In this capacity, sensory memory acts as a kind of filter or clearinghouse, sorting through the cacophony of mostly extraneous incoming information continuously bombarding our senses and channeling only what is important forward for further attention and possible action.

Sensory memory can be demonstrated in a number of ways. If you move your finger back and forth quickly in front of your eyes, you will observe that the image of your finger appears to be in more than one place at a time (a physical impossibility). This is because the visual image of your finger in each location it traverses is held for a brief period within sensory memory after the stimulus (your finger) is no longer there. This persistence of information, albeit brief, makes it available for further processing even after the stimulus has moved or terminated. The brain seems to possess separate sensory memory stores (called *registers*) for each of the sensory modalities—i.e., vision, hearing, touch, smell, and taste. The most extensively studied registers for motor behavior have been those for vision and touch—these are called *iconic* and *haptic* registers, respectively. Visual information is held for about one-half of a second in sensory memory, whereas auditory information is held for a second or longer (some researchers believe for up to about five seconds). However long, this is a brief storage sufficient only long enough for sensory information to be acted upon and either discarded or transferred on for further processing. Most information entering sensory memory (99% or more) is never further acted upon and is lost to the system (i.e., is forgotten) before being transferred for additional processing.

Short-Term Memory

short-term memory: A memory system that holds and operates on information transferred from sensory memory or retrieved from long-term memory; it is under conscious control and capable of operating on only a limited amount of information at a single point in time.

Information that is transferred from sensory for further processing goes to **short-term memory** (abbreviated STM). STM can hold only a limited amount of information, and then only temporarily. When we think about memory, we are usually thinking about STM because it is the only memory system of which we are consciously aware. Whether we are daydreaming, listening to music, solving a mathematics problem, or performing a motor skill, our awareness of our actions is part of STM.

When Atkinson and Shiffrin proposed their three-stage system of memory, they described STM as a "working memory" that was flexible and could be used in many ways in meeting environmental demands. Over the years, this capacity of STM has come to play a central role in the study of learning and cognition among modern theorists, especially those working from a cognitive-based, information processing perspective. STM is viewed today as much more than a passive memory storage system. It is seen as including a temporary workspace in which long-term memories can be retrieved and coupled with current sensory inputs as part of decision-making processes. In modern cognitive-based views, STM is an essential part of conscious awareness, attention, mental activity, and motor control. The coupling of current sensory inputs into STM, attentional processes, and relevant information from long-term memory stores is referred to as **working memory**. Alan Baddeley (2004), describing the functions of working memory as an integral part of STM, has characterized STM as a multicomponent system comprised of an attentional system, a central executive system responsible for cognitive processing of information, and separate subsystems for storage of sensory information. (Although some theorists prefer to view working memory as a separate stage apart from STM, we will follow the more common approach of viewing working memory as a part of STM and shall often use the terms more or less interchangeably.)

working memory: A temporary work space within short-term memory combining incoming perceptions with information from long-term memory.

Because STM is so cognitively intensive, being both responsible for decision making and commanding the musculature to carry out those decisions, it has a limited capacity in terms of the amount of information that can be processed and acted upon at any one time. For many years, scientists studying memory have recognized that there is a fixed, seemingly universal amount of information that can be processed as a single unit of action. This fixed limit on the processing capabilities of STM is known as the **magic number** 7+/−2, and represents the number of **chunks**, or bits of information, that STM is capable of handling in a single process. That is, STM can hold no more than 5 to 9 chunks of information at any point in time; this number establishes a limit to the amount of information that can be acted on as a single unit for purposes of decision making and response. This limit represents the "memory span" of STM.

magic number 7+/−2: The number of chunks, or bits, of information that short-term memory is capable of holding and operating on at any one time.

chunk: A singularly coherent and meaningful unit of information within short-term memory.

The attentive reader has properly already asked, "What is a chunk?" Unfortunately, there is no clear-cut or agreed-upon definition, and answers tend to fall quickly into the quagmire of circular reasoning (i.e., a chunk is what STM

Effective skills instructors understand that beginners have a limited capacity for the number of task-items that they can remember and, therefore, learn during a single practice experience.

can hold about 7 of; STM is the system that can hold 7 chunks). Still, the concept of a chunk, if not the actual definition of it, is fairly well agreed upon. Conceptually, a chunk is a coherent, meaningful amount of information that can be processed as a single unit in memory. A chunk can be a relatively small amount of information, or relatively large, depending on whether the information contained in the chunk can be associated as a single meaningful item for recognition and processing. For example, the letters n, a, l, t, o, p, e, c, a, and u probably represent 10 chunks of information for most people, because there appears to be no logical connection among these letters. In this case, each letter would be encoded, remembered, and processed as a single chunk of information in STM, and because there are 10 letters, this would present a daunting task as it is beyond the memory span of STM (5–9 chunks). However, if one learns to associate all 10 letters in a meaningful way (or recognizes that they already are associated), then the 10 individual chunks can be held and processed in STM as the single chunk *cantaloupe*. The point is that large amounts of information can be handled by STM, as long as it is meaningfully associated into no more than 7+/−2 chunks of information, a technique when used in teaching called **chunking**. Early in learning, before associations among informational units have been made, the capacity of STM for working on information is small; as learning proceeds and associations among informational components are recognized and encoded into memory, more and more information can be held and acted upon at any one time (see Figure 6.4). In a literal sense, learning is about forming associations so that greater amounts of information can be processed in short-term, working memory at a single time.

chunking: The process of grouping skill elements into meaningful units for purposes of instruction.

Just as there is an item limit to the amount of information that STM can process at any single time, there is also a temporal limit to the operations of this

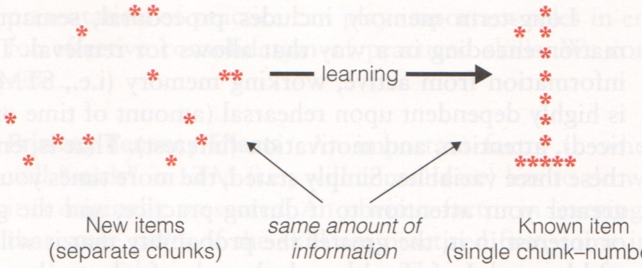


FIGURE **6.4** Effects of "Chunking" New Items into a Single Known Item
Source: Created by author.

stage. Once information enters STM, it can be held—if not acted upon—for only about 20–30 seconds before it dissipates and fades from memory. Information not acted on within this time frame is quickly lost, and cannot be retrieved for further processing or action. With rehearsal (thinking about it, attending to it), however, information can be maintained in STM for a theoretically indefinite period, although most people find it difficult to maintain information for longer than about 8–10 minutes (it is so difficult, in fact, that this figure can be considered an upper limit for STM). As with sensory memory, most information (99% or more) encoded into STM will be permanently lost (forgotten) before being transferred to the next stage of memory—long-term memory.

Long-Term Memory

long-term memory: A memory system that permanently stores all information encoded from short-term memory; responsible for learning.

Long-term memories are those responsible for learning. Once information enters long-term memory (abbreviated LTM), it is more or less permanent (there is some debate about this among experts, but certainly the vast majority of LTMs are stored permanently). LTM contains our memories of past experiences and forms the basis for learning. In fact, by definition, learning means getting things into LTM. Not only is the duration of LTM permanent, but its capacity appears unlimited as well. That is, it is capable of storing an entire lifetime of experiences. Table 6.1 compares the capacity and duration capabilities of long-term memory with the two previous memory stages that we have discussed.

TABLE **6.1**
Characteristics of the Three Stages of Memory

	Sensory Memory	STM	LTM
Capacity	Unlimited	7+/–2 items	Unlimited
Duration	1/10–1 sec.	20–30 sec. or 8–10 min. with rehearsal	Permanent

Long-term memory includes procedural, semantic, and episodic information encoding in a way that allows for retrieval. The process of encoding information from active, working memory (i.e., STM) into permanent LTM is highly dependent upon rehearsal (amount of time or number of trials practiced), attention, and motivation (interest). That is, encoding is a function of these three variables. Simply stated, the more times you practice something, the greater your attention to it during practice, and the greater your motivation or interest in it, the greater the probability that it will be encoded into LTM and learned. In fact, although the role of rehearsal and attention may appear obvious, in regard to motivation it appears to be nearly impossible to form LTMs for something in which a person has absolutely no interest or motivation (which is what typically occurs when people say that they have a learning "phobia" such as math phobia—it is probably not intellectual capability that is lacking, but sufficient interest and motivation to learn). Whether they realize it or not, instructors of motor skills are concerned with the factors responsible for encoding information into LTM when they focus their instructional methods on increasing learners' attention, motivation, and practice time, or with fostering the indestructible vestiges of skill, to echo James (Box 6.6). We will discuss specific instructional methods for facilitating memory for motor skills in Chapters 9 through 11.

Practice Considerations for Enhancing Long-Term Consolidation

An obvious fact concerning the three stages of memory is that the ultimate goal of practice is almost always to encode practiced skills into long-term memory before they are forgotten. The processes by which memories become permanent—that is, transferred into long-term memory structures—is called **consolidation**. According to current thinking, the imprint of experiences takes time to solidify because it requires structural changes in the synaptic connections between neurons, and those changes require time, usually between 24 and 72 hours, to reach fruition (Baddeley, Eysenck, and Anderson, 2009). Over the period of consolidation, the new memory trace is gradually woven into the fabric of long-term memory.

consolidation: The process by which a new memory trace is gradually transferred to long-term memory.

A number of practice variables have been identified that facilitate the process of consolidation. Besides the factors of amount of practice, attention, and motivation, which have already been mentioned and will be given special consideration in later chapters, a number of factors related to the scheduling and

BOX 6.6 William James on the Stages of Memory

The stream of thought flows on; but most of its segments fall into the bottomless abyss of oblivion. Of some, no memory survives the instant of their passage. Of others, it is confined to a few moments, hours or days. Others again leave vestiges which are indestructible, and by means of which they may be recalled as long as life endures.

—William James (1842–1910)
nineteenth-century American
philosopher/psychologist

presentation of practice can play important roles in enhancing the prospects for effective consolidation of practiced skills. We consider several of these next.

Primacy-Recency Effects An important factor in whether new information will "stick" in LTM (i.e., will consolidate) has to do with the order in which it is originally presented. An obvious factor in learning any skill or activity is that some parts of the skill are practiced first, some in the middle, and others last within a practice session. This may seem of no real significance until one considers that the positioning of information during practice has a significant influence on what will be remembered. In fact, the effect on learning of positioning during a practice session is well established across all domains of learning and is called the **primacy-recency effect** (or, perhaps as frequently, the *serial-order effect*).

primacy-recency effect: The phenomenon that information presented at the beginning and ending of a practice session is more readily learned, all other factors being equal, than is information presented in the middle of practice.

The primacy-recency effect is the observation that in any sequencing of things to be learned, those practiced in the beginning (primacy) and ending (recency) of practice will be best recalled. In the practice of motor skills, this means that those activities or components of a skill instructed early and late in practice are the ones most likely to be remembered (i.e., learned), and those in the middle part of the practice session, the least likely to be remembered (i.e., are relatively more difficult to learn). Figure 6.5 illustrates the effects of primacy-recency positioning on remembering and learning.

As can be observed in Figure 6.5, those skill activities or components in the primacy and recency positions of a practice session are most easily consolidated within LTM. That is, all other things being equal, they are most easily remembered and, therefore, the best learned. So instructors of motor skills do well to consider the relative positioning of skills or skill components when instructing new or more difficult skills or activities within practice sessions. Unless there is good reason for doing otherwise, new or more difficult items to be learned should be presented in the beginning and/or ending of practice sessions while reserving middle portions of practice for easier task components or for reviewing previously learned activities.

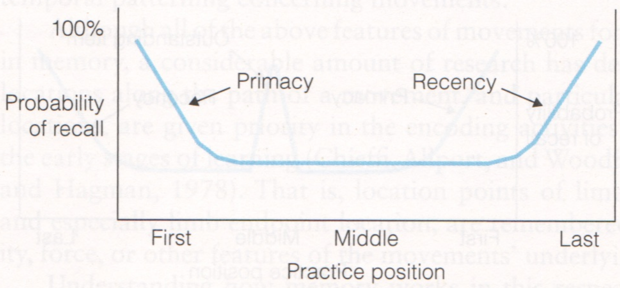


FIGURE **6.5** Primacy-Recency Effects

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The Von Restorff Effect An interesting exception to the primacy-recency effect is that some information presented in the middle parts of practice can be encoded into memory as well as, and perhaps even better than, information presented at either the beginning or ending of practice. This occurs whenever information is given a special meaning, or stands out in some way from other information being presented. An instructor who presents information in an especially dramatic and "unforgettable" way, or who gives special meaning to information or an activity, is relying on the **von Restorft effect** (also called the *outstanding item effect*) to make that information more meaningful and easily remembered by learners (see Figure 6.6).

von Restorft effect: An exception to the primacy-recency effect in that information presented during the middle of a practice session in a particularly meaningful or dramatic fashion increases the likelihood that it will be learned.

Practice Distribution Effects Considerable research across all domains of learning has cogently demonstrated that distributing practice over a longer period punctuated by rest breaks significantly enhances the retention and recall of information (Dail and Christina, 2004). For most cognitively demanding learning situations, which could include preparing for a school examination or practicing a new motor skill, 45 minutes to an hour seems to be an upper limit to the amount of practice time that is effective for learning (Baddeley, 2004). In many situations, even shorter practice periods are recommended. Regardless of the activity, shorter practice sessions distributed across longer periods of time typically result in significant increases in learning (see Figure 6.7).

In practice, the amount of time that motor skill instructors have to work with is often limited by the length of a class, therapy session, or training session. Whenever possible and practical, however, instructors should weigh the benefits to memory of spreading practice out and including more short breaks between practice experiences in order to enhance learning. (The application of this principle should be carefully weighed against other factors, however, and a more extensive discussion of these ideas is presented in Chapter 11.)

priming: The brief introduction of new information prior to the time when it is actually practiced; increases the likelihood that the information will be learned when it is later practiced.

Priming Effects Increasing the likelihood that learners will remember information is significantly enhanced through the use of a technique called **priming**. Priming means the brief introduction of new information or a new skill prior to actually practicing it; priming is presented to help learners "get the idea" of what it is they are going to practice.

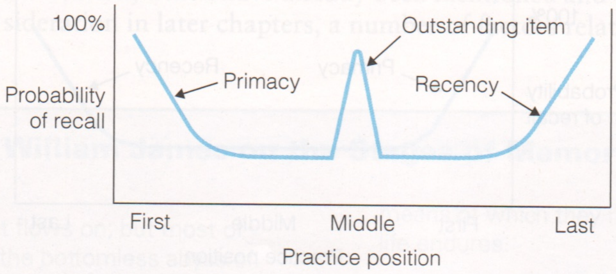

FIGURE **6.6** The Von Restorft (or Outstanding Item) Effect

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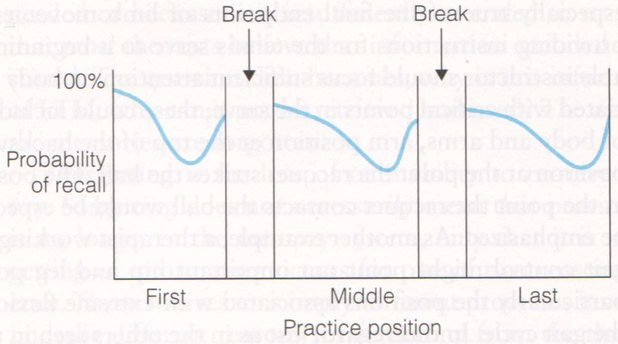

FIGURE 6.7 Effect of Practice Breaks on Recall

Source: Created by author.

Priming can be especially helpful in reducing some retention disadvantages associated with activities practiced in the middle parts of a practice session by briefly introducing the activities at the beginning of practice. Priming activities do not need to be extensive in order to be effective, and in fact probably work best when brief. An instructor who visually demonstrates a new skill at the beginning of practice, for example, even though not instructing it until later in practice, is using priming. Later, when learners practice the skill, the initial priming will enhance the likelihood that they will remember and learn the skill. Priming might also occur at the completion of one practice session for a skill to be instructed on a following day. An important point here is that priming is a brief demonstration designed to help learners get the basic idea of what is to come and is not meant as instruction or practice.

Emphasizing Location Cues When learning a motor skill, any one of many characteristics of movement could be encoded into memory. For example, we could store the location of points along the path of limb movements, the distance of limb movements, the velocity of movements, the force of muscular contractions producing movements, or some abstract representation of spatial-temporal patterning concerning movements.

Although all of the above features of movements for skill are probably stored in memory, a considerable amount of research has demonstrated that various locations along the path of a movement, and particularly movement endpoint locations, are given priority in the encoding activities of memory—at least in the early stages of learning (Chieffi, Allport, and Woodfin, 1999; Diewert, 1975; and Hagman, 1978). That is, location points of limb and body movements, and especially limb endpoint location, are remembered before distance, velocity, force, or other features of the movements' underlying skill.

Understanding how memory works in this respect can aid the instructor of motor skills. Because memory processes function to encode important location points, an instructor can enhance the learning capabilities of individuals by pointing out critical position points in skills being practiced—and this is especially true of the final endpoints of limb movements. For example, when providing instructions for the tennis serve to a beginning learner, a knowledgeable instructor should focus sufficient attention on body and limb locations associated with critical points in the serve; these could include the beginning position of body and arms, arm position at the top of the backswing, and arm and body position at the point the racquet strikes the ball. The position of the striking arm at the point the racquet contacts the ball would be especially critical and should be emphasized. As another example, a therapist working with a patient to regain gait control might point out important hip and leg positions during walking, particularly the positions associated with extreme flexion and extension during the gait cycle. In this regard, just as in the others seen in this chapter, knowledgeable motor skill instructors learn to work with, rather than against, memory.

Sleeping on It The importance of getting a good night's sleep following motor skill practice has been offered as advice by motor skill instructors for as long as anyone can remember. Considerable research in recent years has supported this observation. Sleep following motor skill practice has repeatedly been demonstrated to enhance the learning of motor skills, and even to play an essential role in skill learning (Brashers-Krug, Shadmehr, and Bizzi, 1996; Walker et al., 2002; Walker, Brakefield, and Stickgold, 2003). Although the neural mechanisms connecting sleep and consolidation are still debated, mounting evidence suggests that sleep plays an essential role in the consolidation of memories, and especially in the consolidation of procedural memories.

Although restive sleep is important for optimal skill learning, this should not be interpreted as meaning the more sleep, the better. Sleep representative of a person's normal nightly sleep cycle, which is restful in nature, is sufficient in maximizing consolidation effects. Sleep beyond the normal range appears to have no additional benefits. What is apparent, though, is that a lack of sufficient sleep, or sleep that is interrupted and nonrestful, has detrimental effects on memory consolidation and resultant learning.

More work still is needed to fully understand both the mechanisms through which sleep enhances memory consolidation, as well as the types of skills and individual characteristics which may be most impacted by sleep. Evidence to date would suggest, for example, that younger persons may benefit more from sleep than older individuals, although this is still debatable. Recent evidence also is leading to a conclusion supporting the significant benefits of sufficient sleep in regaining skills lost to injury or neurological impairments (Siengsukon and Boyd, 2009). Other research has shown that the benefits of sleep can be enhanced by short daily naps (Sheth, Janvelyan, and Khan, 2009). Whatever the continuing research in this area ultimately reveals, it is now evident that coaches, teachers, and therapists have been correct all along in encouraging their charges to "get a good night's sleep."

WHY DO WE FORGET LEARNED SKILLS?

In the previous section, we stated that considerable information held in both sensory memory and STM stores is permanently lost, either because it is not needed or because it is insufficiently attended to or practiced. We also noted that most theorists believe that information encoded into LTM is permanently stored. The question then becomes, why is this information lost, or in the case of LTM, why can it not be retrieved and used? The answer in both cases is that the memories are forgotten.

forgetting: The loss of, or failure to retrieve, information from memory.

Forgetting is the loss of or inability to retrieve information from memory. Forgetting does not necessarily mean that previously learned information is no longer in the memory system, only that it is no longer accessible. Forgetting of information occurs for one of two reasons: trace decay or interference. These two reasons imply different processes involved with forgetting and underlie different reasons for forgetting from the three stages of memory. We will examine both reasons for forgetting as well as the implications for motor skill practice.

Trace-Decay Theory

trace decay: A theory of forgetting that the memory trace fades over time and reverts to its original state; an explanation of forgetting from sensory memory and short-term memory.

Trace-decay theory is probably what most people think about when they think about forgetting. Trace decay means that the original memory trace stored in one of the memory systems decays before being permanently encoded in LTM. The original excitation of neurons in the brain (the memory trace) caused by electrochemical activity transmitted from sensory receptors diminishes over time as energy is dissipated. Once the original trace is gone, it can no longer be retrieved (because it is no longer anywhere in memory). The process of decay may take only a fraction of a second in sensory memory, or between seconds

BOX 6.7 A Hierarchy of Memory Difficulty

Things are difficult or easier to remember based upon a number of factors. Donald Norman (1988), a noted cognitive scientist, summarizes the ease with which things are remembered as falling into the following three categories.

1. **Memory for arbitrary things.** The items or information to be retained seem arbitrary, with no meaning and no particular relationship to one another or to things already known. This represents the category of things that are the most difficult to remember.

   Example: Teaching the serve in tennis by presenting the individual components of the swing in isolation (i.e., rotate at the hips, lead with the elbow of the striking arm, snap the wrist at contact, etc.).

2. **Memory for meaningful relationships.** The items or information to be retained form meaningful relationships with themselves or with other things already known. This category represents only moderate difficulty of remembering.

   Example: Illustrate how the tennis serve uses the same movement pattern as throwing a ball.

3. **Memory through explanation.** The material does not have to be remembered, but rather can be derived from some explanatory mechanism. This represents the easiest category of remembering.

   Example: Build upon the illustration of throwing a ball by explaining the biomechanical principles involved (i.e., rotating the hips and leading with the elbow increases the distance the racquet head travels prior to contacting the ball, thus increasing speed and force at contact).

and minutes in STM. In either case, information that is not transferred to the next stage of memory vanishes due to trace decay and are eliminated from the system and further processing activities. Trace decay is the explanation for forgetting from both sensory and STM. Some information that originally enters LTM may also be lost to trace decay if it is not made permanent through sufficient rehearsal and attention, though this conjecture remains debatable. Once the memory trace is encoded in LTM, its structure and function are immutable to decay, and so trace decay is no longer an explanation for forgetting. If the trace is impervious to decay, though, why do people forget information stored in LTM? The answer is not that the trace decays, but that interference prevents retrieval of the memory.

Interference Theory

interference: A theory of forgetting that memories encoded into long-term storage may fail to be retrieved into short-term memory because other memories stored in the long-term system block retrieval processes.

Interference theory is the notion that memories in LTM interfere with, or get in the way of, one another (Baddeley, Eysenck, and Anderson, 2009; Del Ray, Liu, and Simpson, 1994; Keppel and Underwood, 1962; and Underwood, 1957). The problem is not that memories stored in LTM diminish in strength in any way, but that they cannot be effectively retrieved. Because LTM is such a vast store of memories, those covering a lifetime of experiences, it should not be surprising that memories can interfere with one another. Put simply, given the vast number of memories stored in LTM, so many are similar in some respect that finding the correct one becomes a challenge to memory's retrieval capabilities.

Not all memories have the same potential to interfere with one another, however. Two factors seem especially important in determining the strength of interference between any two memories; these are their similarity and their temporal closeness. That is, the more two memories are similar—the more they are about the same thing—and the closer together in time they were originally registered in LTM, the greater the potential for interference between them to occur.

The storage of information with respect to the comparative time in which memories are placed into LTM has an effect on the strength of interference, and further denotes two types of interference effects called *retroactive inhibition* and *proactive inhibition* (which are also termed *retroactive interference* and *proactive interference*).

Retroactive Inhibition

retroactive inhibition: The interference of newer memories with retrieval of older memories.

Retroactive inhibition (see Figure 6.8) refers to the interference of new memories with the retrieval of older memories. (Another way of saying the same thing is that new learning interferes with old learning.) We have all experienced that as things we once learned and knew well recede in time without being practiced, we tend to forget them. This is because the things we have subsequently learned affect our ability to recall previous memories. It is, of course, to our benefit that memory is structured in a way making what we are currently experiencing more readily accessible to recall and use (think what it would be like if you could remember everything you did a year ago, but had trouble remembering what you did earlier in the day). Still, retroactive inhibition can become problematic relative to skilled performance, especially when skills are not continuously practiced.

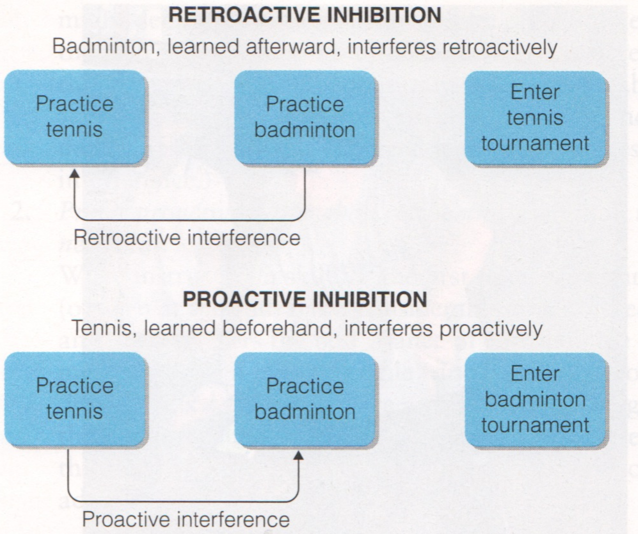

FIGURE **6.8** Retroactive and Proactive Inhibition

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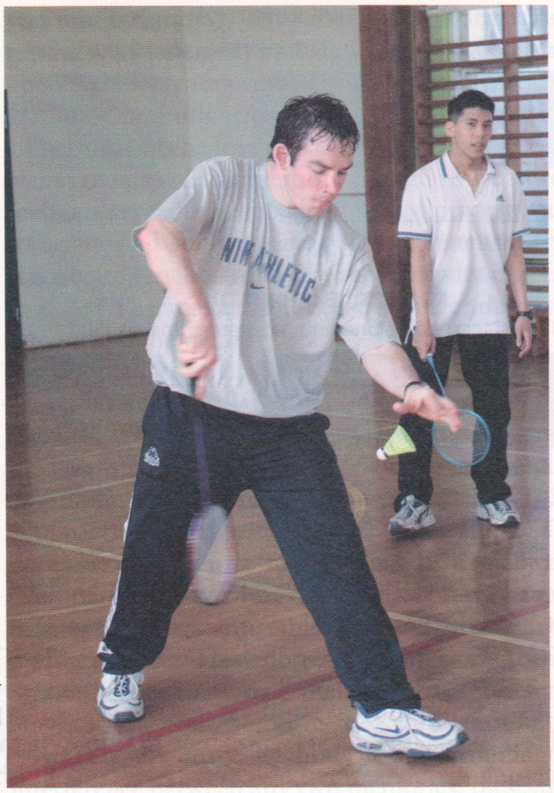
Skills that are learned and then not used for long periods of time are susceptible to retroactive inhibition. Since the time of the first scientific studies on forgetting by the German psychologist Hermann Ebbinghaus (1885, 1913) in the late nineteenth century, it has been known that the rate at which newly presented information is forgotten is steep. Although many factors affect the rate of forgetting, a generalized finding is that about 70 percent of the information originally recalled in a practice session is forgotten within the first 24 hours after practice, and that figure quickly increases to about 80 percent after 48 hours. After that, the rate of forgetting gradually diminishes over longer periods of time, with perhaps no more than 5 or 10 percent of the originally learned information ultimately retained (or, at least, accessible). The effects of retroactive inhibition can be significantly decreased in several ways, however. These include following overlearning practice schedules, as discussed earlier, in Chapter 5, providing for periodic refresher practice of skills, and using mental rehearsal of skills during periods of nonuse. The type of skill also interacts significantly with rates of forgetting, with continuous motor skills considerably more resistant to forgetting than are discrete motor skills.

Proactive Inhhibition

proactive inhibition: The interference of older memories with the learning and retrieval of newer memories.

Proactive inhibition (see Figure 6.8) refers to the interference of old memories with the retrieval of newer memories. (Again, another way of saying the same thing is that old learning interferes with new learning.) A common example of proactive inhibition is seen when experienced racquetball players attempt to learn tennis; their previous learning of racquetball interferes with their initial ability to learn tennis.



Mike Booth/Alamy

Individuals who take up the skill of badminton after having learned tennis, often experience an initial period of difficulty acquiring the correct racquet techniques for badminton because the differences in racquet techniques between tennis and badminton are a source of proactive interference.

Of the two types of inhibition, though, retroactive inhibition causes considerably more problems during learning and is the stronger of the two types relative to interference effects.

Strategies for Reducing Interference (and Forgetting)

Based on an understanding of interference and the effects it has on memory and learning, the motor skill instructor can apply several principles to the design of practice experiences that will increase the likelihood learners will successfully remember what they practice. These principles inform the following two guidelines, which would be well considered in the teaching of any motor skill.

1. *Separate similar skills within a practice schedule as far apart as "practically" possible in order to reduce the effects of interference.* For example, a dance instructor teaching several different steps to a class

might determine which of the steps are most alike and then separate them so that instruction initially occurs on different days. (Note that this goes against much commonly heard advice about teaching similar skills together, which can be effective but only once some initial degree of learning has occurred making memories more resistant to interference.)

2. *Prefer proactive rather than retroactive inhibition when presenting a new skill.*

When instructing a skill for the first time, presenting it late in practice (or even at the end) has a considerable effect on reducing interference and gives learners the best chance of encoding the skill and getting it into memory while it is still "fragile" and susceptible to interference. Practice does not need to be extensive at this stage, although somewhat more than an introduction is probably desirable. (The reader will note that this consideration based upon reducing interference effects also takes advantage of primacy-recency effects.)

The secret of a good memory is attention, and attention to a subject depends upon our interest in it. We rarely forget that which has made a deep impression on our minds.

—Tryon Edwards (1809–1894)

Putting together the several principles discussed in this section on forgetting, the motor skill instructor should be able to design effective practice schedules giving learners the best chance of retaining information and acquiring desired motor skills.

MEMORY AND PLACE: ENCODING SPECIFICITY PRINCIPLES

By now, the reader will hopefully recognize that memory impinges upon nearly every aspect concerned with the learning of motor skills. Because of this, most practice considerations are based at least to some extent, and often to a great extent, upon memory principles. In focusing on memory, however, it is easy to consider only those aspects of practice of which we are consciously aware and which seem directly related to skill performance. After all, it is what we attend to, what we are consciously aware of wanting to learn, that is encoding into memory. Or is it?

When we learn a motor skill, we consciously practice and hopefully encode into long-term memory the important aspects of bodily movements required for executing a skill properly. We also remember, again hopefully, strategies for executing the skill under various conditions. Such information forms what is called **explicit memory**. These are memories of the things we consciously intend to learn, and of which we are consciously aware when we retrieve them. But there are also other facets of learning environments that are encoded and stored along with explicit memory, those of which we are unaware and which we do not intend to remember. We might think of these features as a backdrop of the practice environment, something like the canvas of a painting. When we look at a painting, we are aware of the various images portrayed, the colors, the background on which the figures are displayed, indeed all of the visual elements and details the artist placed upon the canvas. We probably do not think about the canvas itself, however. Yet it forms the supporting surface making the painting possible.

explicit memory: Memory that is open to intentional retrieval (synonymous with declarative memory).

When we learn a new skill, many features of the practice environment form the supporting background of practice; they are like the canvas on which an artist paints. We may not be aware of them, but they provide the context in which those aspects of practice of which we are aware are embedded, and much of this background context is stored in memory along with the explicit memories we intend to learn. These memories are called **implicit memories**, and they are entwined with our explicit memories of a skill so that memories are really compositions of both consciously and unconsciously learned elements of the practice environment.

implicit memory: Retrieval of information from long-term memory through performance rather than conscious recall; nondeclarative memory.

In learning a motor skill, we store in memory information pertaining to movement patterns, the goals and rules of the skill, and perceptual cues related to the performance of the skill—all things we intentionally practice and of which we are aware. These are all explicit memories. But we also encode into memory many aspects related to the conditions of learning of which we are not consciously aware—or at least which we do not intentionally practice and intend to remember. These implicit memories may include aspects of the place in which we practice the skill such as specific spatial dimensions related to performance (extent and distances of the practice space), lighting conditions, patterns of color and texture, temperature, time of day, verbal feedback, the order in which skill events are typically sequenced during practice, the way in which skills are practiced (active vs. passive, or slow vs. fast, for example), social conditions (how we relate to those with whom we practice), and even mood (our level of arousal, attention, motivation, etc.). None of these aspects of practice are things we specifically pay attention to with the intention of remembering them as they relate to learning a skill; nonetheless, they are (or many such aspects are) encoding into memory along with the more obviously practiced elements of a skill.

Researchers have observed for many years that when the original conditions of practice change, people have some increased difficulty in recalling learned information. This is true for both declarative and procedural memories, including memories for motor skills (see Tulving and Thomson, 1973). Scientists call the conditions of learning in which memories are originally formed the **encoding condition**. The conditions existing later, when a person attempts to perform the skill, are called the **recall condition**. The closer the encoding and recall conditions resemble one another (the more similar they are), the easier it will be to retrieve the memory of a skill and perform it well (Magill and Lee, 1987; Thompson and Madigan, 2005). The observation that retrieval and performance of learned skills are facilitated to the degree that encoding and recall conditions are similar is known as the **encoding specificity principle**.

encoding condition: The context in which a skill is practiced and learned.

recall condition: The context in which a skill is performed as a result of practice.

encoding specificity principle: The principle that skills executed in situations similar to those in which they are learned will be better remembered and performed.

A Classic Demonstration of the Encoding Specificity Principle

Godden and Baddeley demonstrated the encoding specificity principle in a landmark experiment in 1975. Their experiment consisted of training 60 experienced scuba divers to recall a list of 36 nonassociated words practiced under one of two conditions. Half of the divers practiced learning the list on the dock next to the water, while the other half practiced for the same amount of time but 15 feet underwater a few feet away from the dock. On the following day, all divers were asked to recall as many of the words on the list as they could. During the recall test, however, half of each group was asked to recall the list of words in the same setting as they were originally learned, and the other half of the group was asked to recall the list in the opposite setting. That is, half of the divers who practiced on the dock performed the recall test on the dock, while the other half performed the test underwater. Likewise, half of the group who practiced underwater performed the recall test underwater, while the remaining half performed the test on the dock (see Figure 6.9).

Results of the experiment revealed that both groups remembered best when they were tested in their original learning condition. On the other hand, attempting to recall the list of words in the opposite condition resulted in considerably less proficiency for both groups. The group that learned on the dock correctly recalled 37 percent of the words on the list when tested on the dock, but only 23 percent when tested underwater. The group that learned the list underwater successfully recalled 32 percent of the words when tested underwater, but only 24 percent when tested on the dock (see Figure 6.10). Godden and Baddeley concluded that the similarity of contexts between learning and recall conditions provided retrieval cues, whereas the greater forgetting in the dissimilar contexts was due to the absence of context-dependent retrieval cues encoded along with the original learning.

Encoding Specificity and Practice Guidelines

Since Godden and Baddeley's original study, many other experimental investigations have established the principle of encoding specificity (e.g., Lee and Hirota, 1980; Magill and Lee, 1987; Smith, Glenberg, and Bjork, 1987; Smith and Vela, 2001; and Vaidya et al., 2002). What this principle means for instructors of motor skills is that the closer practice conditions (i.e., encoding

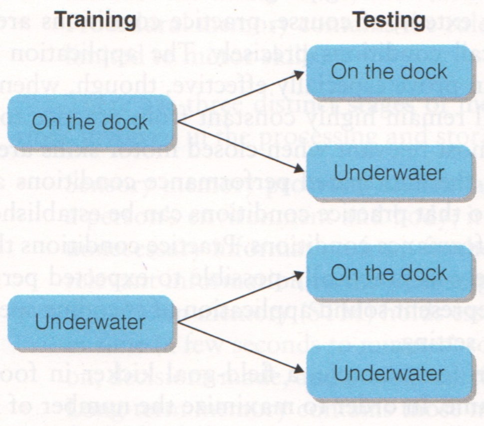


FIGURE **6.9** Experimental Design of Godden and Baddeley Study

Source: Created by author.

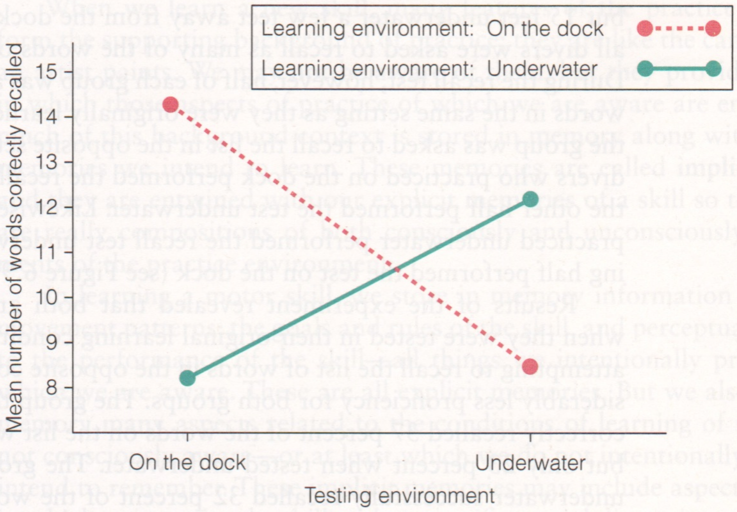


FIGURE 6.10 Results of Godden and Baddeley Study

Source: Created by author.

conditions) are matched to those conditions in which a learner is ultimately expected to perform (i.e., recall conditions), the more effective practice will become. Examples include matching practice conditions as closely as possible to game conditions in the practice of athletics, clinical conditions to home or work conditions in therapy settings, training conditions to work conditions in industrial training programs, and training conditions to expected combat conditions in military training programs.

To some extent, of course, practice conditions are seldom able to mimic expected recall conditions precisely. The application of encoding specificity principles can prove especially effective, though, when both the practice context and skill remain highly constant from practice to recall conditions. This situation is most relevant when closed motor skills are being instructed. With closed skills, the anticipated performance conditions are typically stable and predictable so that practice conditions can be established to closely mirror the expected performance conditions. Practice conditions that are designed to conform as closely as practically possible to expected performance conditions in these cases represent sound application of encoding specificity principles to the instructional setting.

Consider, for example, a field-goal kicker in football practicing for an upcoming game. In order to maximize the number of kicks practiced, he will kick many balls. Most of these will be kicked in isolation from his teammates, under nonpressured conditions, while setting his own pace concerning when to kick the ball. None of these conditions will exist in the actual game, however, in which he will be called upon to perform quickly when the ball is snapped and with the sights and sounds of opposing players closing in on him. In this case, it is particularly important that as many kicking attempts as possible during practice be accomplished under more authentically game-like situations as part of practice with the entire team during game-simulated conditions.

As another example, it is interesting to observe the efforts made to provide realistic skill performance situations in professional police and military training programs. Once basic skills have been acquired, both military and police personnel are put through training that is as close to the expected actual conditions of policing and combat as possible, including environmental considerations such as location, time of day, lighting, weather, ambient noise (sirens, explosions, shouting, etc.), and obstacles—all of this while wearing their service uniforms complete with webbing, utility belts, and backpacks.

SUMMARY

Learning is made possible by memory, which most simply defined is the capacity to maintain some aspects of previous experiences in order to guide current behaviors. The mechanisms responsible for memory are viewed differently within cognitive-based and dynamical systems theories.

Memory is comprised of the declarative and procedural memory systems, with the declarative system further subdivided into semantic and episodic subsystems.

- The semantic memory system stores generalized knowledge about the world; it includes memories about objective and nonpersonal facts and events.
- The episodic memory system stores information about personal events; it includes the what, where, and when of personal experience.
- Procedural memory contains the rules governing skills, including but not limited to motor skills.

There are three distinct stages of memory, each devoted to specific functions involved in the processing and storage of information.

- Sensory memory processes all available sensory information from a person's environment and body; it acts as a filter, eliminating unnecessary information from further consideration and transferring relevant information to the next stage for further processing.
- Short-term memory (STM) holds essential information for a brief period of time (a few seconds to minutes) so that it can be consciously worked on, decisions made, and actions carried out.
- Long-term memory contains those memories that have been permanently stored in memory, and it is the system ultimately responsible for learning (i.e., learning occurs when what has been practiced gets into long-term memory).

The consolidation of long-term memories (learning) can be significantly enhanced through instructional techniques based upon memory considerations including chunking, primacy-recency effects, the Von Restorff effect, practice distribution, priming effects, and the emphasizing of location cues.

Forgetting is the loss of or inability to retrieve and use information stored in memory. An important goal of practice is the presentation of information in ways that learners are less likely to forget it. Two theories, trace-decay theory and interference theory, explain why people forget.

- Trace decay occurs when the original neural trace associated with an event or practice experience decays or dissipates before becoming permanently encoded into LTM.
- Interference occurs when a memory has been encoded permanently into LTM, but other memories interfere with a person's ability to retrieve and use the memory. Interference can occur through either retroactive or proactive inhibition.

When practicing skills, both explicit and implicit aspects of the practice context are encoded into long-term memory.

- Retrieval of the memory for a skill is facilitated to the degree that the encoding and retrieval conditions are similar.

The study of how memories for motor skills are formed provides many important guidelines for the provision of practice experiences and instructions. Knowledgeable practitioners learn to work with, rather than against, memory.

LEARNING EXERCISES

1. For this exercise, identify a setting of interest to you in which you can observe an instructor teaching a motor skill to either an individual or small group of individuals in the initial or early stages of learning for at least 30 minutes (larger groups may be used if you are still able to closely observe the instructor). Describe the setting, including the methods you used for observing and collecting data.

   Prior to making your observations, discuss with the instructor his or her goals for the practice session, a description of previous practice activities if any, and whether the instructor uses any specific teaching methods based upon memory considerations. Once observing the practice, your goal is to analyze the effectiveness of the instructional setting in relation to considerations concerning memory. Make a list of memory considerations you think relevant to the situation and for which you will make observations (e.g., are primacy-recency considerations observed, are chunking methods employed, are important location cues pointed out, etc.? Many more items can be included). As you observe practice, keep notes on your observations.

   After your practice observations have been completed, prepare a written evaluation of your experiences and conclusions. Discuss those aspects of instruction that reflected good techniques for facilitating the memory of learners, as well as ways in which practice could have been instructed to produce greater memory consolidation and later recall of skills. How would you have instructed practice differently based upon your understanding of memory?

2. Design a practice schedule for instructing a motor skill in which you are both interested and knowledgeable to an individual having no previous experience with the skill. Describe the basic activities in which this learner will engage for a period covering the initial 10 practice periods. Describe in general terms your instructional goals for each of the practice sessions. Describe for each practice session how memory considerations will help you achieve your practice goals, including specific techniques you will use in providing instructions.

3. For this exercise, describe a motor skill in which you are experienced and believe yourself highly proficient and one in which you are inexperienced and would like to become better. Provide a detailed description of how you believe you use your memory when performing both of these skills. Specifically, how do both declarative and procedural memories help you describe and understand your performance characteristics for both skills?

FOR FURTHER STUDY

HOW MUCH DO YOU KNOW?

For each of the following, select the letter that best answers the question.

1. The process by which information in the environment is translated into a form that can be registered by a memory system is called
   a. storage.
   b. consolidation.
   c. retrieval.
   d. encoding.
2. Studies in the 1950s with a young man identified only as "H.M." resulted in the discovery of
   a. the memory trace.
   b. the procedural memory system.
   c. episodic memory.
   d. convergence centers.
3. In a series of items practiced in the order A, B, C, D, E, F, G, H, I, and J, assuming all items are of equal difficulty and new to the learner, which items would most likely be the easiest to remember and therefore the most likely to be learned?
   a. A, B, C, and D
   b. G, H, I, and J
   c. A, B, I, and J
   d. D, E, F, and G
4. Forgetting from short-term memory is explained by ___(1)___, while forgetting from long-term memory is explained by ___(2)___.
   a. (1) trace decay, (2) interference
   b. (1) proactive inhibition, (2) retroactive inhibition
   c. (1) interference, (2) trace decay
   d. (1) retroactive inhibition, (2) proactive inhibition
5. Which of the following is a characteristic of short-term memory?
   a. Is capable of storing an unlimited amount of information
   b. Has a duration capacity of one second or less
   c. Has an item capacity of five to nine chunks or bits of information
   d. Stores information in the form of schema