11

MEMORY AND FORGETTING

Memory is the storage and retrieval of what is learned, forgetting is its loss, and retention is observable evidence of its durability over time.

CHAPTER OBJECTIVES

After studying this chapter, you should be able to:

- Explain the contemporary concepts of human memory that have guided research during the past three decades.
- Identify the areas within the central nervous system that appear to play important roles in memory-related functions, and explain how they operate.
- Explain and give examples of the different types of memory and how they contribute to the learning of movement skills.
- Distinguish among the terms memory, forgetting, retention, and learning.
- Explain and give examples of how memory, forgetting, and the retention of motor skills are scientifically studied.
- Explain how to control for variables that can confound temporary performance effects with the effects due to memory and forgetting.
- Explain the theories of forgetting, and provide examples of how they work.
- Explain and be able to describe the factors that influence the long-term retention of movement skills.
- Explain and give examples of the techniques and strategies a practitioner and/or clinician can employ to enhance the learning and retention of movement skills.

How is it that we are able to remember hundreds of seemingly unrelated events, countless procedures for assembling equipment or operating a computer, and the abstract rules associated with playing a particular game or solving a complex mathematical equation? The answer to this question appears to lie in a construct known as *memory*. Gordon (1989) states that "the term *memory* is most often defined as an internal record or representation of some prior event or experience" (p. 9). Thus it is intimately related to learning, which we discussed at length in Chapter 6.

In this chapter you will learn about memory and its role in the learning and forgetting of movement-based skills. In Chapter 6 we described *motor learning* as a process by which the capability for producing movement performance (an internal state that cannot be directly observed) and the actual movement performance (which can be directly observed) are reliably changed through instruction, practice, and/or experience. The storage and retrieval of this learned capability for producing the reliable change in movement performance is the process of **memory.** Thus, motor learning is the acquisition of the capability for generating the reliable change in movement performance, while memory saves it over time and retrieves it when needed.

In contrast, **forgetting** is a process that refers to the loss of the ability to effectively store and retrieve the learned information needed for producing a reliable change in movement performance. The persistence with which learned changes in movement performance can be demonstrated over time without practice (**retention interval,** or **RI**) is referred to as **retention.** Remember that motor learning, memory, and forgetting are internal processes that operate within the learner and, therefore, cannot be directly observed and measured. What *can* be directly observed and measured is the learner's motor performance in acquisition and on tests of retention. Thus, we use the motor performance directly observed and measured in acquisition and retention as evidence from which to make inferences about the memory and forgetting of learned movement skills. For instance, acquisition performance that is retained on a retention test following an RI is inferred to be learned. Conversely, acquisition performance that is not retained over an RI on a retention test is inferred to be forgotten. Whether this retention loss and inference about forgetting actually represents a memory loss of the learned capability for producing the acquisition performance or whether the learned capability is at full strength in memory and simply can't be retrieved is a matter of some uncertainty and continued debate.

Is memory a structure that can be traced to a particular area of the brain or somewhere else in the nervous system? Or is memory best conceptualized as a cognitive process that enables us to act upon a continual flow of externally and internally generated information in a meaningful way? This is just one of the many questions addressed in this chapter. No doubt many more questions will emerge as the discussion unfolds, and some will remain unanswered at its conclusion. Let us begin our discussion by describing two contemporary yet contrasting views of the construct called memory.

Contemporary Concepts of Memory

Numerous attempts by researchers to describe the intricacies of human memory have yielded a variety of theories and models over the years. One has only to read the literature to encounter descriptions of memory that range from reverberating circuits in the brain (Hebb, 1949) to computer analogies wherein memory is likened to a central processing unit consisting of a set of structures through which all information must pass. Two contemporary concepts of memory that have contributed to a renewed research interest in human memory over the past three decades are discussed in this section. The first of these two concepts

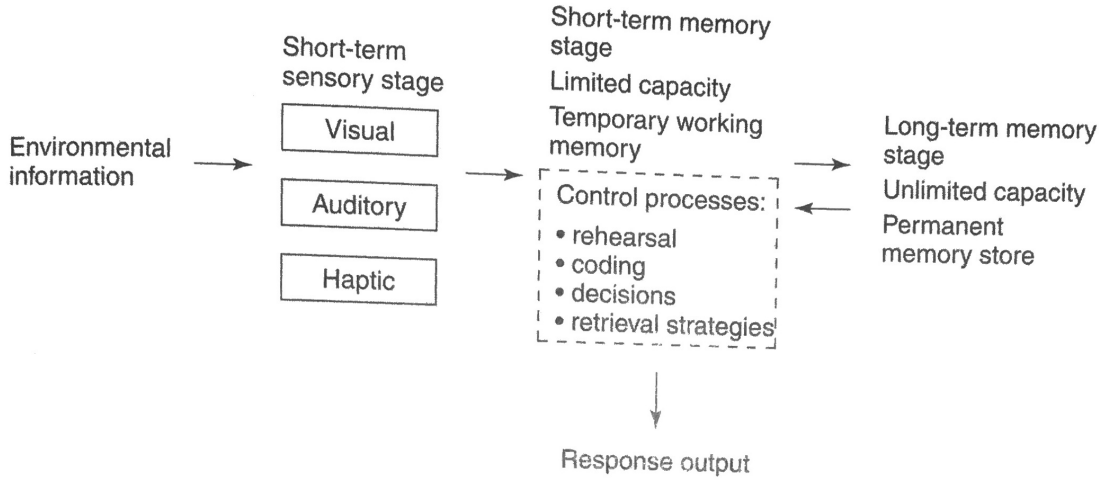


Figure 11.1 The Atkinson and Shiffrin multistore stages of memory consolidation model.

Source: Atkinson, R. C., & Shiffrin, R. M. (1971). The control of short-term memory. *Scientific American, 225,* 82–90.)

represents a more structural view of memory. The second proposes an alternative view that emphasizes a more functional approach to the study of memory.

Atkinson and Shiffrin's Multistore Model

One of the most highly developed multistore models of memory was proposed and empirically tested by Atkinson and Shiffrin (1968, 1971). Their model was based on the **consolidation theory** of memory that was originally proposed by Müller and Pilzecher (1900). In the earlier theory, it was suggested that information is initially stored in some pattern of dynamic electrical activity that gradually leads to structural changes in the brain. The idea that learning and memory could involve changes in the neuronal circuits was incorporated in a conceptual framework that was developed by Hebb (1949) and described in his book, *Organization of Behavior.* Essentially, he hypothesized that the memory for something learned is due to activity in a *cell assembly,* in which nerve cells are connected together in special circuits and that, when a nerve cell is active, its synaptic connections become more effective. This effectiveness may be reflected in a temporary increase in the synapse's excitability, as in short-term memory, or it may involve some long-lasting structural change in the synapse, as in long-term memory.

According to the multistore model, human memory consists of clearly defined structures in which various types of processing occur.

The ideas that plastic changes at synapses are the underlying mechanisms of learning and memory and that brain functions are mediated by cell assemblies and neuronal circuits have become widely accepted. Although the specific details of consolidation theory have varied somewhat among scholars, there were enough common elements for Atkinson and Shiffrin (1968, 1971) to propose their multistore model of memory (see Figure 11.1). Drawing

heavily on the computer analogy, they conceived of human memory as a set of clearly defined structures (hardware) in which various types of processing occurred (software). Atkinson and Shiffrin distinguished among these hypothesized memory stores on the basis of their different retention characteristics and the types of processing activities that took place in each. The processing activities included such things as memory coding, rehearsal, organization, and retrieval of information from memory. Each process was also considered to be under the control of a processor that used each of these **mnemonic strategies** to move information through the system in a highly regulated fashion.

According to the **multistore model of stages of memory consolidation,** environmental information enters the first of three stages, called a **short-term sensory stage (STSS).** This relatively large-capacity store is responsible for registering the physical features of an environmental display provided by any and all of our sensory systems (e.g., visual, auditory, haptic). These features registered might include the shape of an object, the feel of a surface, and sound coming from a nearby location. In order to preserve the information entering the STSS, however, an individual must attend to it or it will decay and be lost in a period of 30 seconds or less.

Once the selected information is transferred to the next stage of this multistore model, we become consciously aware of its presence. In this second memory stage, which the authors refer to as **short-term memory (STM),** much of the active processing necessary to transfer the selected information into the third stage for more permanent storage takes place. Unlike the STSS, the STM is much more limited in its capacity but capable of more sophisticated processing. One control process in particular serves an extremely important function in this stage of memory. This process, called **rehearsal,** is important for the maintenance and/or elaboration of information reaching the STM and for its subsequent transfer to the third memory stage.

Much of the active processing necessary to transfer information to LTM occurs in STM.

This final stage, known as **long-term memory (LTM),** is viewed as a relatively permanent store with an essentially unlimited capacity for storing information. It is here that the individual is thought to store knowledge of the world in various forms. These various forms include important facts (declarative knowledge), operations (procedural knowledge), and/or concepts (semantic knowledge). Although it is represented only once in the model constructed by Atkinson and Shiffrin, the STM is actively involved in the flow of information before it actually reaches LTM. For example, information entering the STSS cannot be labeled or categorized until it is compared with information already stored in the LTM. Similarly, the strategies that govern the movement of information through the system must first be represented in the LTM in the form of rules or principles.

The multistore model developed by Atkinson and Shiffrin has guided research in the area of human memory during the past three decades. It has been used to describe how adult memory operates and has also proved to be an effective framework for interpreting age-related changes in various aspects of memory capability (Chi, 1976, 1977; Ornstein, Naus, & Liberty, 1975).

Levels-of-Processing Framework

Despite the evidence compiled in support of Atkinson and Shiffrin's multistore model of memory, a growing number of researchers began to question the usefulness of this approach. Two particularly avid critics of structural accounts of memory were Craik and Lockhart (1972; see also Craik 1977; Cermak & Craik, 1979), who viewed the phenomenon of memory very differently. Unlike other cognitive psychologists of that time, they believed that research attention should be directed solely toward better understanding of the processes used to acquire, store, and then recall memories. They further argued that clear demarcations between the various structures of memory were not so distinctive as previously thought and that the projected capacity of each store could be significantly influenced by other variables. These might include the type of information processing necessary or the time available to process the incoming information. Craik and Lockhart were to develop an alternative memory framework—the **levels-of-processing framework**—that focused on how information was processed at different levels within a unitary memory structure.

The levels-of-processing framework focuses on the processing of information at different levels within a unitary memory structure.

Craik and Lockhart proposed that memory of an event (e.g., movement skill) depends on the *depth* to which the event is processed. The greater the depth of processing, the more elaborate and durable the memory of the event. They believed that two primary factors determined how much information was eventually stored in memory. These were (a) the number of memories an individual was capable of processing at any one time and (b) the depth to which the incoming information was processed. The authors realized that not all the information presented to an individual at any given time could be processed and that, therefore, the learner needed to choose which information would be processed. Craik and Lockhart hypothesized that although the most recently presented information was more likely to be processed, given its importance in changing the nature of the problem being explored or the action being performed, the performer could also choose to continue processing previously presented information. Information processed by the learner constituted *primary memory;* the remaining, unprocessed information occupied *secondary memory.* An individual could then choose to process the information at a shallow level or at progressively deeper levels that provided a greater opportunity for elaborating the information or rendering it more distinct in some way.

They envisioned shallow levels of processing as being concerned with analysis of the sensory or physical features of the incoming information related to the event. Deeper levels of processing involved matching the incoming event information with a stored abstraction from past learning. Based on this concept of a hierarchy of processing levels, memory of an event depends on the depth of processing, as well as other variables such as the amount of attention devoted to the event, its compatibility with the analyzing structures, and the processing time available. Memory was linked to levels of processing and was viewed as a continuum extending from simple sensory analysis to abstract associative functions; therefore, memory depended on the depth to which sensory events were analyzed, rather than the amount of processing. Later, Craik (1977) and Craik and Tulving (1975) modified the original framework by proposing that it was the degree to which the sensory event was elaborated rather than the depth to which it was processed that determined whether it became a persistent memory trace.

Addressing the relevance of the level-of-processing approach to memory for movement skills, Lockhart (1980) indicated that the ability to remember a movement skill is influenced by the degree to which the performer can make use of his or her existing skills to structure and perceive meaning in the skill. Memory depends upon the degree to which the performer's skills and the structure of the movement skill itself allow processing of increasing depth. If the levels-of-processing approach has relevance for the memory of motor skills, it is to point out that movement skills have meaning in the sense that they have internal structure, purpose, and function. The extent to which the performer's perception provides an analysis of this meaning and the capacity to reconstruct it will determine the memory of a movement skill.

Like Atkinson and Shiffrin's model, Craik and Lockhart's alternative framework for studying memory has had its critics (Baddeley, 1978; Morris, Bransford, & Franks, 1977). The major criticisms include there being no way to measure the depth to which information was processed, a problem Craik and Tulving (1975) were unable to solve, and the framework's preoccupation with how information is encoded in memory as opposed to how it is retrieved. Finally, one of the strongest criticisms of this framework came from Glanzer and Koppenaal (1977b), who argued that it was not actually a rival of consolidation theory or the multistore model proposed by Atkinson and Shiffrin. They considered both theories as representing a single approach to the study of memory with the term *stages* heavily used in consolidation theory and the Atkinson-Shiffrin multistore model, and the label *levels* heavily used in the levels-of-processing framework.

Neurobiology of Memory

A question one might aptly raise at this point is whether there is any neurological evidence in support of Atkinson and Shiffrin's structural claims or any areas within the nervous system capable of serving the type of processing functions described by Craik and Lockhart. Certainly, the interest in human memory has not been confined to a psychological level of analysis. It has fascinated an equal number of neuroscientists, who have attempted to identify regions within the nervous system that might subserve memory. A review of their research efforts and limited findings is the topic of this section.

The search for neuroanatomical sites corresponding to memory dates back to ancient times and the study of phrenology, a pseudoscience whose adherents traced the contours of the skull in an attempt to reveal an individual's character and mental faculties. Today, the experimental paradigms and measurement techniques used to study memory are not only more sophisticated, but also more extensive in scope. They range from the ablation and lesion techniques used to study memory in animals (Lashley, 1950; Mishkin, 1982) to the use of contemporary brain mapping and scanning techniques, such as positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and transcranial magnetic stimulation (TMS) that were discussed in Chapter 2. These imaging techniques have made it possible to identify areas within the brain that are active during the performance of different types of memory tasks (Ungerleider, 1995). Systematic clinical observations of patients with neurological damage that has caused different types of amnesia have also

helped researchers identify areas in the human nervous system that may be involved in several important memory functions.

One early pioneer in memory research was Karl Lashley (1929, 1950), who spent a number of years trying to identify specific brain structures that might be responsible for coding and storing mnemonic information. Using an animal model to study memory, Lashley systematically ablated or introduced lesions to increasingly large areas of an animal's cortex. The results of his work indicated that how well the animal was able to remember a given task was determined primarily by the total amount of cortex destroyed rather than by the specific region affected. Lashley's conclusions were to become the cornerstone of a memory principle called **equipotentiality:** the idea that no one area of the cortex is more likely than any other to be involved in the storage of memories.

Early research revealed that no one area of the cerebral cortex is more involved than any other in the storage of memories.

Although this same distributed view of memory still exists today, researchers have begun to identify distinct anatomic structures and areas within the CNS that support different types of memory. These different memory systems have been broadly divided into two categories: **declarative (explicit) memory** and **nondeclarative (implicit) memory** systems (Squire & Knowlton, 1994; Squire & Zola, 1996). Before identifying the different neural structures associated with each of these different memory systems, let us first discuss how these systems differ from each other. First, declarative memory involves the memory for events, facts, and concepts. These memories might involve activities that you can remember doing on a particular day last week, the rules of a sport or game you play, or what happened on a certain date in history. These memories are consciously remembered. In contrast, nondeclarative memories are acquired at a subconscious level and are associated with such things as learned skills or procedures that can be easily performed but not as easily described verbally. Habits that we acquire are also examples of nondeclarative memories.

Neural structures identified with the storage of declarative memories include the medial temporal lobe and structures within the diencephalon that include the hippocampus and the parahippocampal, perirhinal, and entorhinal cortices. In contrast, the neural structures involved in the storage of nondeclarative memories include the striatum, the cerebellum, and the prefrontal, somatosensory, motor (M1), and occipital cortices. The occipitotemporal cortex, amygdala, and spinal cord have also been identified in the storage of nondeclarative memories as well as different types of learning (associative and nonassociative).

Specific neural structures have been identified as being involved in the storage of different types of memory and learning.

How is it that these different types of memories are stored in the brain? The general consensus among researchers is that highly selective changes in the strength of synaptic connections between neurons are at least partly involved in the development of memories. Although it is beyond the scope of this book to describe the exact mechanisms involved in the storage of memories, a number of animal studies suggest that changes in the existing neural circuitry are associated with short-term forms of memory while the storage of long-term memories is associated with a sequence of processes that culminate in the growth of new synaptic connections. (See Baxter & Baxter, 1999, for a more detailed review of the neural mechanisms associated with learning and memory.)

Types of Memory

Short-Term and Long-Term Memory

The temporary storage of information in short-term memory enables us to compare and contrast stored items.

Short-term memory, or working memory (Baddeley, 1981) as it is often called because of its active role in the processing of information, is assumed to contain all the information we are currently thinking about or are conscious of at any particular point in time. How much information is this component of memory capable of storing at any given time? Miller (1956) proposes that we are capable of temporarily storing as few as five separate units of information to as many as nine individual units. Given this limited capacity of working memory, it is fortunate that phone numbers rarely exceed seven digits in length and that social security numbers are limited to nine! The temporary storage of information in working memory also enables us to compare and contrast the items being held there and even to associate current information with information that has previously been stored in a repository of more nearly permanent memory known as long-term memory.

Unlike STM, LTM is considered to have a limitless capacity for the storage of information. Moreover, once the information to be retained has been transferred to this large-capacity store, it is believed to remain there for an almost indefinite period of time. You will recall that the control process Atkinson and Shiffrin identified as instrumental in the transfer of information from short-term to long-term memory is rehearsal.

Long-term memory has been described as a relatively permanent storage area for memories, but it is not uncommon for us to be unable to remember an event witnessed many years ago or to find ourselves unable to perform a skill we had learned as a child. Although some researchers attribute the tendency to forget information already stored in long-term memory to the natural decay of the memory trace over time, others argue that forgetting is caused by different types of interference. Still more recently, a number of researchers have begun to turn to alternative explanations of forgetting that focus on the larger issue of retrieval failure. These contemporary theorists acknowledge that interference plays a role in forgetting, but they consider it only one explanation for our inability to retrieve information from memory. More will be said about theories of forgetting later in this chapter.

Declarative and Procedural Memory

Declarative memory assists us in knowing "what to do," whereas procedural memory assists in knowing "how to do" a particular skill.

A second way of categorizing memory has been proposed by a number of researchers (J. R. Anderson, 1981, 1987; Tulving, 1985) interested in distinguishing among different types of memory on the basis of the types of knowledge stored there. Although Tulving originally proposed three types of memory (episodic, procedural, and semantic), there has been a tendency to describe only two types of memory: declarative memory and **procedural memory** (Anderson, 1987).

"Knowing *what* to do" in any movement situation is an important part of the learning process and appears to be subserved by declarative memory. Information stored in this area of memory may include the rules of a game, the components of a skill, or the facts of a particular situation. In contrast, procedural memory assists us in "knowing *how* to do" a particular skill.

The Relationship Between Learning and Memory

Gordon (1989) has characterized the relationship between learning and memory as one where learning acts as the trigger or catalyst for the formation of memories and/or knowledge about a particular action. In light of the importance of this relationship between memory and learning, we will examine it more closely in this section.

In attempting to describe the way the role of memory changes during the acquisition of cognitive skills, Anderson (1982) has developed a theoretical framework that is highly reminiscent of Fitts' (1964) three-stage model of motor skill acquisition (see Chapter 6). According to Anderson, during the first stage of learning a cognitive task, information about the skill is encoded as factual or **declarative knowledge**. This type of knowledge can be interpreted and then used to generate a solution. In this stage, a learner may continually rehearse the information presented in order to hold it in working memory for later interpretation. The overt signs of this rehearsal may include mutterings or visible lip movements.

The process of knowledge compilation is used to convert knowledge from a declarative to a procedural form.

As the learner enters the second stage of learning, the existing knowledge is gradually converted from a declarative to a procedural form. This process of **knowledge compilation** not only vastly reduces the burden placed on working memory's small capacity, but also enables the learner to apply the knowledge directly to the task at hand. There is no longer a need for intermediary interpretation of the factual information, which tends to be slow and prone to error. Recall that Fitts described a similar transition stage at the behavioral level. He characterized the second associative stage of learning as one in which performers begin to blend individual components of a motor skill into a smooth sequence of movements.

During the final stage of learning, which Anderson called the procedural stage, learners continue to fine-tune their **procedural knowledge** to a level where it can be quickly and appropriately applied to a specific problem. The sequence of productions that are performed can be likened to a set of cognitive steps one might use to structure a geometry proof or perhaps to move a chess piece into a "checkmate" position. Anderson's three-stage description has been applied primarily to the acquisition of cognitive skills, but it can be useful in describing the role of memory in the learning of many different types of motor skills.

How Memory and Forgetting Are Studied

Memory and forgetting of motor learning are processes that are studied by directly observing and measuring motor performance not only in acquisition, but also on a retention test following an RI. Based on the extent to which the most proficient level of motor performance achieved in acquisition is retained on the retention test following an RI, we draw our inferences about the memory or forgetting of motor learning. If the motor performance achieved in acquisition is retained, then it is reasonable to infer that it was learned. Conversely, if the motor performance in acquisition was not retained, then it is reasonable to infer that it was forgotten. Thus, inferences about the memory or forgetting of motor learning are based on retention performance. Of course,

Inferences about memory and forgetting processes are based on retention performance.

for such inferences to be valid there must be experimental control over variables not being studied (manipulated) that could operate and temporally influence motor performance during acquisition, or over an RI, and even on a retention test. Two such variables that frequently seem to be operating to confound their effects with those due to memory and forgetting include conditions of warm-up and motivation. (These two variables will be discussed in more detail later on page 334.)

Often there is some confusion over the exact meaning of the terms *retention* and *transfer* of motor learning—and for good reason. Some of the experimental designs and procedures used to study them appear to be very similar. Moreover, learners cannot transfer motor performance that they have not retained, so there is a very close relationship between them. To avoid such confusion, we will use the term *retention* when performance on the motor task practiced during the acquisition phase is assessed in the retention phase under conditions that are essentially the *same* as those that existed in the acquisition phase. The term *transfer* is used when the motor task and/or conditions present in the retention phase *differ* from those that existed in the acquisition phase. A number of issues related to the transfer of motor skill learning will be discussed more fully in Chapter 12. It is important to understand the concept that retention, as defined above, is actually a special case of transfer.

Retention and transfer are related in the sense that the post-acquisition context can differ from the acquisition context along the dimensions of time and overall similarity. The RI acquisition and post-acquisition contexts tend to become less similar because the mechanisms that affect the emotional, physical, and cognitive states of the learner are operating. For instance, the mechanisms that produce forgetting or that change one's motivation to perform can operate during an RI. In this sense, a retention test can be interpreted as a test of the transfer of motor learning to contexts that appear to match the context of the acquisition phase.

What Retention Test Performance Tells Us

When we study motor performance in the acquisition phase we are studying the learning of a defined motor performance. However, when we study motor performance on a retention test, we are studying the durability of that learned performance over time.

Retention performance tells us something about the durability of the motor performance learned in acquisition.

In other words, we are studying the retention of motor learning over some RI. It is easy to make the mistake of thinking that retention performance is a direct measure of the durability of motor learning when, in fact, it is a direct measure of retention performance from which we draw our inferences about the memory and forgetting of motor learning. Retention performance measures tell us something about the durability or reliability of motor performance that was learned in acquisition, and we use that information to make inferences about memory and forgetting processes.

Retention test measures are direct measures of the retention performance from which inferences can be made about how much motor learning was remembered (memory) or lost (forgotten) over an RI. Performance measures in *acquisition* (e.g., performance curves) are used to help us make inferences about mechanisms, processes, and outcomes of motor learning. Performance

measures in *retention* are used to help us make inferences about memory and forgetting processes that operate over the RI to affect the durability of the motor performance that was learned in acquisition.

Generally, the level of motor performance achieved in acquisition is assessed in post-acquisition with a retention test for at least two major reasons:

- To determine if the performance observed is temporary and due to variables that do not qualify as evidence for motor learning (e.g., fatigue, drugs, level of motivation) or if it is durable and the result of variables that do qualify as evidence for motor learning (instruction, practice, augmented feedback, and experience)
- To study the extent to which the level of motor performance achieved in acquisition is retained as a function of variables manipulated before, during, and after acquisition, as well as during the RI in order to make inferences about memory and forgetting. For example, we might study the retention of movement skills as a function of variables such as (a) practice distribution in acquisition, (b) amount of practice in acquisition, (c) duration of RI, and (d) motor responses learned before acquisition of the motor response to-be-recalled (proactive interference) or after it (retroactive interference).

Explicit tests of motor retention can tell us something about **recall memory** and **recognition memory.** Recall tests require a learner to retrieve the criterion movement from memory and perform it when the appropriate stimulus is presented. For example, we might ask a right-handed golfer to recall and perform the swing with a five iron that will move the ball from left to right with a high trajectory. On the other hand, recognition tests require a learner to indicate with an identification response whether the criterion movement was experienced before. For instance, we might ask a learner to try gripping the tennis racquet in different ways prior to executing a particular serve to see if he or she recognizes any of them as ones experienced before when serving well. Typically, explicit motor retention tests are more tests of recall than recognition. However, the relative roles of recall and recognition probably interact quite often. For instance, a criterion movement (e.g., a golf putting stroke or a particular tennis serve) that cannot be recalled at one moment can be recalled at a later time with the appropriate cueing (stimulus) from a teacher or coach.

Retention tests that ask learners to retrieve the criterion movement and perform it are assessing recall memory.

Retention tests that ask learners to identify whether the criterion movement was experienced before are assessing recognition memory.

Frequently, individuals have information stored in memory from implicit learning, but they have difficulty retrieving it on explicit retention tests because they are unaware of the information that was learned. For example, in motor learning, **implicit learning** could refer to improvements that occur in learners' capability to perform a movement skill as a result of practice and without their being aware of the parts of the movement skill that led to the improvements. **Explicit retention tests** are those that directly ask people to consciously remember (recall or recognize) what was learned. Asking a learner to perform a previously learned movement skill would be an example of an explicit retention test. The retention tests we discussed in the previous paragraph and earlier in this chapter are examples of explicit tests of memory. **Implicit retention tests** are ones in which people are asked in different ways

Implicit retention tests ask learners in different ways to demonstrate or report whether they have something in stored memory of which they are unaware.

to demonstrate or report whether they have something stored in memory of which they are unaware and, therefore, have difficulty retrieving for an explicit test.

A study by McPherson and Thomas (1989) provides a nice example of explicit and implicit retention tests in the movement domain of sport. They asked young male basketball players to complete a paper-and-pencil test by indicating what they would do in various game situations (explicit test). Thus, this explicit test was trying to find out if they remembered what to do (declarative knowledge). For their implicit test, they observed what the players actually did in the various game situations to determine if they possessed the procedural knowledge needed to do what they reported they should do on the explicit test. Their findings indicated that many of the players knew what to do in various game situations (declarative knowledge) but couldn't perform accordingly (procedural knowledge).

Retention tests also can provide us with useful information about intentional and incidental memory. When people know in advance that the movement skills presented to them or practiced by them will have to be recalled and performed later on a retention test, we are studying **intentional memory.** Conversely, if they do not know in advance that the movement skills presented to them or practiced by them would have to be recalled and performed later on a retention test, we are studying **incidental memory.** Essentially, these two types of retention test situations are used to investigate memory as a function of one's *intention* to remember.

Comparing the retention findings of the two situations can answer questions about the intention to remember and encoding of movement information processes. For instance, do we retain more of or perhaps only the information to which we consciously attend, as in the case of intentional memory? To what extent do we retain information to which we do not consciously attend? Questions such as these have been the focus of very little research in movement skills. However, the research that is available reveals that the intention to remember produces better retention than no intention to remember and that no intention to remember results in better retention than if no previous experience with the movement skills had occurred. (For a review, see Crocker & Dickinson, 1984.) One instructional implication from this research is that the retention (memory) of motor learning can be enhanced by telling participants at the outset of acquisition exactly what type of information they will be tested on and how they will be tested at a later time.

Example of How the Retention of Motor Learning Is Studied

When studying motor retention, traditionally a distinction is made between the acquisition and retention phases of an experiment as shown in the example in Table 11.1. In this example, we are studying how well movement A is retained as a function of different retention intervals (RIs). The acquisition phase could consist of a set number of performance trials for all three groups, or it could involve the time or trials required for the groups to achieve a criterion level of proficiency in performing movement A. The retention phase follows the acquisition phase and consists of an RI and a retention test. The

Table 11.1
Experimental Design to Study the Retention of Motor Learning

Acquisition Phase		Retention Phase	
Group	Learn	Retention Interval (RI)	Retention Test
I	Movement A	3 months	Movement A
II	Movement A	6 months	Movement A
III	Movement A	12 months	Movement A

RI is a time period of nonuse or no practice of movement A; it can vary from being short (e.g., seconds or minutes) to long (e.g., weeks, months, or years) in duration. The retention test is used to determine how much of the movement A proficiency achieved in acquisition is retained when it is performed again after an RI or, alternatively, how many trials are saved in relearning the movement (known as a *savings score,* which is discussed on page 338).

Let's describe a published experiment as an actual example of how retention of motor learning is studied. Ryan (1965) studied the retention of stabilometer performance (a novel dynamic balancing task) over the three RIs shown in the preceding experimental design to study motor learning. The swinging motion of the stabilometer board was recorded by a counter, which produced a performance score that served as the outcome, or dependent measure of interest. The less the movement of the stabilometer board, the better the total body balance and the lower the performance score. A three-trial pretest was administered to provide a basis for matching and assigning participants to groups on the acquisition trials, familiarize participants with the stabilometer, answer questions related to performance of the task, and establish a basic relationship with the participants. After three days of no practice, the three groups returned for the acquisition phase and performed eleven 30-second trials on the stabilometer with a 30-second rest between trials. Following RIs of 3, 6, and 12 months, the groups performed a retention and relearning test in the retention phase of the study. Relearning consisted of the groups performing eight 30-second trials with a 30-second rest between trials. The results are shown in Figure 11.2. Essentially, this figure reveals considerable decrements in stabilometer performance over the RIs, with the longest RI resulting in the greatest decrement. All three groups demonstrated a significant decrement in performance on the first trial of the retention phase, with the group having the 12-month RI experiencing the greatest reduction in performance proficiency. Stabilometer performance was quickly relearned for the groups that had 3- and 6-month RIs, but the group that had the 12-month RI took longer to relearn than either the 3- or 6-month group and never acquired the level of performance achieved in acquisition. Thus, a savings score could not be calculated for the 12-month RI group.

It is worth pointing out that the results may have been different if more acquisition trials had been administered. Acquisition performance on the stabilometer has been shown to improve after as many as 60 trials. Thus, it may be that the retention decrements observed in Ryan's study were the result of incomplete learning and that, if more acquisition trials had been provided,

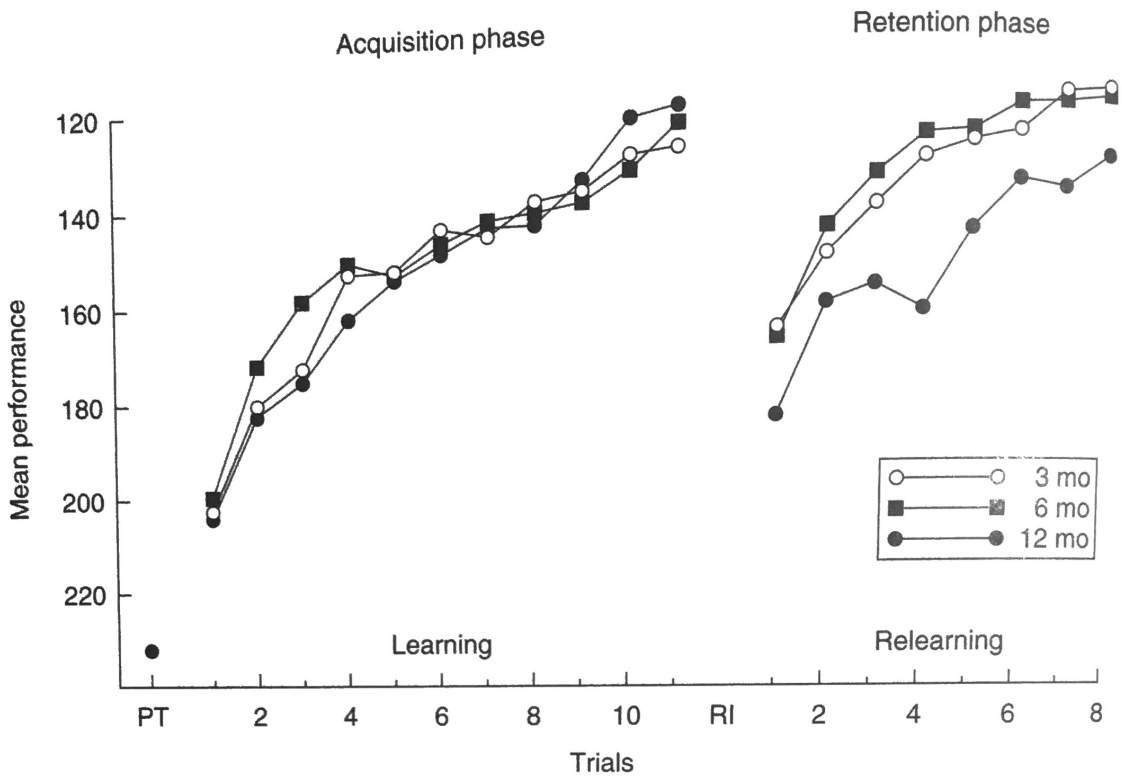


Figure 11.2 Mean stabilometer performance for learning and relearning following three different retention intervals of 3, 6, and 12 months

PT = pretest; RI = retention interval

Source: Adapted from E. D. Ryan (1965). Retention of stabilometer performance over extended periods of time. *Research Quarterly, 36,* 46–51.)

then the losses might have been less. Further, it is likely that in relearning the 12-month RI group would have returned to the level of performance achieved in acquisition, thereby making it possible to calculate a savings score.

Controlling for Variables That Produce Contaminating Effects

If certain variables are allowed to operate uncontrolled, their effects will be confounded with those due to memory and forgetting.

As was pointed out previously in this chapter and in Chapters 6 and 7, when we assess the reliability or durability of motor learning that occurred in the acquisition phase, care must be taken through our experimental design and procedures to control or account for the temporary effects due to variables such as warm-up conditions, level of motivation, distribution of practice, reminiscence, and common daily variations in motor performance that could operate during an RI to affect retention test performance. The effects on acquisition and retention performance produced by these variables do not qualify as evidence for motor learning or the memory or forgetting of motor learning and thus are considered contaminating effects. If these variables are allowed to operate uncontrolled, their temporary effects on performance will be confounded with the effects on performance due to motor learning, memory, and forgetting. Let's look at some examples of how such confounding could occur and what can be done to avoid it.

Example 1: Inappropriate RI. It is well known that massed practice (continued practice with little or no rest between trials) can depress performance in acquisition, which is a temporary effect. Longer RIs would allow more time for the massed practice effect to dissipate and thus make retention test performance less contaminated by this temporary effect. However, longer RIs could produce a more proficient level of performance on the retention test for the massed practice group than was ever achieved in acquisition. This improvement in retention performance over an RI has been called **reminiscence.** A reminiscence effect reveals that a more proficient level of motor performance was retained after the RI than was ever achieved in acquisition, whereas we would expect less to be retained if forgetting was operating.

The effect due to reminiscence is the opposite of the effect caused by forgetting, which makes these opposing effects somewhat challenging to interpret. A similar effect could occur for longer RIs as a result of a change in motivation. For instance, suppose a massed practice schedule led to increased physical fatigue and boredom as practice of a gross motor task (e.g., stabilometer or Bachman ladder) continued in acquisition. As a result, acquisition performance was depressed for the massed practice group because they gradually lost some motivation to perform as practice continued. A short RI (e.g., 1 minute) would not provide enough rest for much of the physical fatigue and boredom to dissipate and appreciably increase the group's motivation to perform on the retention test. However, a sufficiently long RI (e.g., 15 minutes) would allow these negative effects to dissipate, resulting in an increased motivation to perform on the retention test. The result would be a reminiscence effect, that is, a more proficient level of performance on the retention test than was achieved in acquisition.

In order to interpret a reminiscence effect of a massed practice group, it must be compared to the acquisition and retention test performance of a distributed practice group. For example, suppose a longer RI results in retention test performance of the massed practice group being about the same as the distributed practice group. This finding suggests that the massing of practice depressed performance in acquisition but had no effect on learning as evidenced by the retention test performance. Thus, reminiscence effects due to massed practice or changes in motivation can be interpreted if the temporary effects of these two variables are controlled and accounted for with complete experimental designs that include all the necessary control groups and procedures to effectively manage the distribution of practice and level of motivation of the participants.

Of course, longer RIs would also allow other variables to affect performance. For example, inappropriately warming up or motivating participants to perform could cause a decrement in retention test performance. At the same time, longer RIs could result in increased levels of forgetting, but it would be difficult to determine how much of the retention performance decrement was due to forgetting because it would be confounded with the effects caused by inappropriately warming up and motivating participants to perform. Thus, the use of retention tests to assess the reliability or durability of motor learning or to study memory and forgetting of motor learning could confound the amount learned in acquisition with warm-up and motivation if they operate over the RI and if our experimental design and procedures do not control or account for their effects (for a more detailed discussion, see Christina & Shea, 1988, 1993).

Example 2: Contaminated Retention Test Measures. Retention test measures (discussed on page 338) that do (relative retention scores) and do not (absolute retention scores) make use of acquisition performance measures also could be contaminated with temporary effects caused by independent variables being manipulated in acquisition (e.g., massed practice, lack of motivation) such that they might not reflect motor learning. Some researchers have assumed that these effects are present only when the independent variables are present. However, temporary performance effects (e.g., due to massed practice) can persist and be present on the retention test well after the independent variables are removed in acquisition. For example, suppose we were studying stabilometer performance as a function of practice distribution. Certainly, it is reasonable to expect practice distributions with shorter intertrial rest intervals (more massed practice conditions) to require longer RIs of rest for the temporary performance effects (e.g., physical fatigue) to dissipate than will practice distributions with longer intertrial intervals (more distributed practice conditions). Further, if shorter RIs of rest are not long enough for all of the temporary effects to dissipate, then retention test performance (usually measured by an absolute retention score, discussed on page 338) would contain different amounts of temporary effect contamination, depending on the practice distributions used in acquisition. In other words, retention test performance resulting from the more distributed practice conditions probably would have less contamination than retention test performance resulting from the more massed practice conditions. Moreover, if we compared retention test performances of the different practice distributions, we would be taking the risk of comparing performances that not only could have different amounts of learning and forgetting, but different amounts of temporary effect contamination as well.

Appropriate experimental designs and procedures can control variables that cause contaminating effects.

Clearly, retention test performance can be easily contaminated by variables that cause temporary performance effects not only when they are present, but also after they are removed if their effects persist over the RI and into the retention test. One way to control these variables that cause temporary effects on performance is through the careful development of the experimental design and procedures to be used in the study. Certainly, one important design feature would be to include an RI of sufficient length. A single RI can be justified if there is evidence from other studies and/or your own pilot studies that all the temporary effects due to variables such as massed practice, warm-up, and level of motivation have dissipated over that RI.

Without this evidence, you may have to use more than one RI. In some situations, the presence of temporary performance effects can by assessed reasonably well by the administration of both immediate and delayed retention tests (Christina & Shea, 1993). In the case of an immediate retention test, the retention interval should be the same as the intertrial interval during the acquisition phase of the experiment. For both the immediate and delayed retention tests, the acquisition groups should be tested under the same experimental conditions.

A more definitive description of temporary performance effects might be obtained if conditions were included in the experimental design in which the independent variable (e.g., KR) was left intact for the retention tests. Presumably, temporary performance effects would still be present for the immediate retention test for all conditions but would have the opportunity to

dissipate by the time of the delayed retention test. This would especially be the case for the conditions in which the independent variable of interest was removed for the retention tests.

Example 3: Inappropriate Warm-Up. All retention performance decrements are not due to memory losses or forgetting. As has been pointed out previously, some are due to variables such as warm-up and motivation. Warm-up is a unique variable that deserves some special attention. It is not uncommon to observe a decrement in retention performance following acquisition and an RI. If the experiment is properly designed, we would interpret this decrement to memory loss or forgetting. However, some scholars have argued that this decrement is due to the lack of properly warming up and thus it is a **warm-up decrement** (Adams, 1952, 1961).

The decrement in retention performance may be due to forgetting or to inappropriately warming up.

Two hypotheses have emerged to explain warm-up decrement. The **forgetting hypothesis** proposes that the loss in retention performance is, in fact, due to forgetting. It is just another form of forgetting or loss of memory for performing the motor skill. The rest over an RI allows certain forgetting processes to operate, with the beginning stages of these processes being relatively rapid, which accounts for the rather sizable decrements in retention performance observed with only a few minutes of rest. The initial improvements in performance with practice during the retention phase that erase the warm-up decrement are thought to be due to relearning of the aspects of the motor skill that were forgotten.

In contrast to the forgetting hypothesis, the **set hypothesis** holds that the decrement in retention performance is due to a loss of set, which is a relatively temporary loss of bodily adjustments or internal states that support the memory of the capability for performing the motor skill at a proficient level as it was performed in later stages of acquisition. The set hypothesis argues that little or no forgetting has occurred over the RI and that the memory of the capability for performing the motor skill is largely intact. What initial practice in the retention phase (which could be considered warm-up practice) does for the learner is to reinstate the lost set, causing performance to rapidly improve and erase the decrement. Evidence from Schmidt and colleagues (Nacson & Schmidt, 1971; Schmidt & Nacson, 1971; Schmidt & Wrisberg, 1971) supports the set hypothesis. Moreover, evidence from imagery practice involving mental performance of the motor skill immediately before actual performance is resumed appears to reduce the warm-up decrement, but the nature of the reduction seems to be skill specific (Ainscoe & Hardy, 1987; Anshel & Wrisberg, 1988, 1993; Wrisberg & Anshel, 1993).

In summary, there may be some slight losses of memory or forgetting of the capability to perform a motor skill over short RIs (e.g., minutes), but the existing evidence largely favors the loss of set (internal adjustments) over the RI. The implication for studying memory or forgetting processes is that warm-up must be controlled, manipulated, or accounted for in the design and procedures of the experiment. One way to do this is to have participants in experimental and control groups perform an unrelated movement task during the RI just prior to the retention test. This sounds easy, but often it is difficult to find an appropriate movement task that is unrelated to the movement task to be recalled and performed on the retention test and can serve to eliminate warm-up decrement. If warm-up is not controlled, the decrement in retention

performance that is due to not warming up properly will be confounded with the decrement that is due to forgetting. Such uncertainty about the cause of the decrement in retention performance severely limits the inference that can be made about the decrement being due to memory loss or forgetting.

Retention Test Measures

Several measures have been used to assess performance on the retention test following acquisition and an RI. The most frequently used measures include an absolute retention score, savings score, and relative retention score. Each of these three measures is briefly discussed below.

Absolute Retention Score. This score is the first-trial recall score or the actual performance on the initial trial of the retention test. Using the data shown in Figure 11.2 on page 334, we can estimate the absolute retention scores on the first trial of the retention phase to be approximately 165, 167, and 183 for the 3-month, 6-month, and 12-month RI groups, respectively. If all variables that cause temporary performance effects are controlled through the study design and procedures, the **absolute retention score** reflects the amount retained of what was originally learned in acquisition.

The absolute retention score represents the amount of acquisition performance retained after the RI.

We would like to point out that, although one expects absolute retention scores to indicate the amount retained and relative retention scores to reveal the amount of performance lost over an RI, there are a few times when they do not. For instance, under certain practice conditions (e.g., massed practice), absolute retention scores can reveal more retained than what was learned in acquisition and relative retention scores can show improvement or gain rather than loss in performance over the RI. This reminiscence effect was discussed on page 335.

Compared to a distributed practice schedule, a massed practice schedule temporarily depresses performance in acquisition but appears to have little or no effect on learning. When this temporary effect dissipates with rest over the RI (if it is long enough), retention test performance of the massed practice group usually improves and is equal to or approaches the performance of the distributed practice group. More importantly for our discussion, retention test performance of the massed practice group is better than it was at any time in acquisition. Consequently, when one calculates an absolute retention score, the massed practice group actually retains a higher performance level than was achieved in acquisition. Similarly, when one calculates either of the relative retention scores, the massed practice group actually shows a gain rather than a loss in performance over the RI from the end of acquisition.

The savings score is the number of trials or time saved in relearning a skill.

Savings Score. The **savings score** is the number of trials or time saved in *relearning* a motor task that was originally learned in the acquisition phase. To calculate this score, you simply count the number of trials in the retention phase required for learners to reach the level of proficiency in performance that they achieved in acquisition. This number is then subtracted from the number of trials needed to originally learn the task in acquisition. The difference between the two scores constitutes the savings score. For example, using the data in Figure 11.2, it appears that it took the 3-month RI group 5 trials and the 6-month RI group 6 trials to relearn the stabilometer task. It also took both groups 11 trials in acquisition to reach the highest level of proficiency in

performance in acquisition. Subtracting 5 from 11 results in a savings score of 6 trials for the 3-month RI group, while subtracting 6 from 11 produces a savings score of 5 for the 6-month RI group. A savings score could not be calculated for the 12-month group because they were not given enough trials in relearning to reach the level of performance they achieved in acquisition. However, it is clear that the 12-month group would have needed more relearning trials than the other two groups to reach the level they achieved in acquisition.

It is also possible to express a savings score as a percent retention score simply by dividing the savings score by the number of trials needed in acquisition to achieve the criterion level of performance, and then multiply by 100 to convert to a percentage. For example, using the 3-month RI group, simply divide 6 (savings score) by 11 (acquisition trials needed) and multiply by 100 to obtain the retention score of 55%. In this case the savings score of 6 trials, otherwise known as the retention score, is 55%. Conversely, the amount not retained (forgotten) would be 45%.

Christina and Shea (1993) encouraged the study of relearning in the retention phase by using the savings score in conjunction with the absolute retention score. By doing this, a more comprehensive assessment of retention performance could be performed and inferences about memory and forgetting processes more confidently made. Clearly, these two measures, used in combination, can tell us more about retention performance than only one of them. For example, based on an extensive literature review, Adams (1987) concluded that the "forgetting of procedural responses can be complete in about a year, although there are savings because relearning is rapid" (p. 54). Thus, learners might show little or no retention based on their absolute retention score on the first relearning trial but demonstrate a substantial savings in the number of trials required to relearn the skill (their savings score). In this situation, the absolute retention score tells us that nothing was retained of what was originally learned, but the savings score indicates that at least some skill-related information was retained. It is clear that if only the absolute retention score is used, the conclusion reached might be very different from the one reached when both scores are used.

Relative Retention Score. Another way to assess retention is with a **relative retention score,** which actually reflects how much performance achieved (learned) in acquisition was lost or not retained over the RI. Two relative retention scores often used are a difference score and percent relative retention score. A **difference score** is the difference between performance achieved on the last trial or block of trials of acquisition and performance obtained on the first trial or block of trials of the retention test. For example, let's assume from the data in Figure 11.2 that the performance score on the last trial in acquisition for the 3-month RI group was 130 and that it was 165 on the first trial of retention. The difference between these two scores is 35, which represents the amount of balance performance that was lost or not retained (forgotten) over the 3-month RI. Thus, the difference score actually measures how much performance declined over the RI from the end of acquisition to the retention test.

The difference score and the percent relative retention score indicate the amount of performance lost over the RI.

A **percent relative retention score** is the difference score divided by the amount of change in performance during acquisition, which is then multiplied by 100 to convert it into a percentage. For example, let's estimate from the

data in Figure 11.2 that the first trial performance score in acquisition for the 3-month RI group was 204 and that it was 130 on the eleventh trial of acquisition. Subtract 130 from 204 to get the amount gained in acquisition (74) and then divide the difference score (35) by the amount gained in acquisition (74), which results in a quotient of 0.47. Lastly, multiply 0.47 by 100 to convert it into a score of 47%. This percent relative retention score represents the decline in performance over the RI relative to the amount of improvement in performance achieved during the acquisition phase. Thus, it assesses the amount of improvement in performance observed in acquisition that was not retained over the RI.

Contrasting Retention Test Measures. Obviously, the retention test measures discussed in the previous section are based on performance and are used to draw inferences about forgetting. These measures are subject to the same difficulties as performance measures obtained in acquisition (e.g., performance/learning curves) that are used to draw inferences about motor learning. You will recall that these types of measures were discussed in Chapters 6 and 7. We must always be mindful that performance in acquisition is no more a perfect index of motor learning than it is in retention for memory or forgetting—performance in acquisition and retention can be temporarily affected by variables such as a massed practice schedule, fatigue, level of motivation, and drugs that do not reflect motor learning, memory, and forgetting processes. Performance scores taken in acquisition and retention also can be affected by measurement limitations such as scoring sensitivity and ceiling and floor effects that were discussed in Chapter 7. Armed with an understanding of the limitations of performance measures as indicators of motor learning, memory, and forgetting, our inferences about these processes are likely to be made on solid ground.

It is not uncommon to find results from studies based on different retention measures that appear to be in conflict and lead to divergent inferences about motor learning, memory, or forgetting. For example, retention can be measured using an absolute retention score or a relative retention score. If forgetting is measured with an absolute retention score, we find that absolute retention increases with increases in the amount of original learning. However, if forgetting is measured by either of the relative retention scores, we find that relative retention decreases with increases in the amount of original learning (that is, amount of practice in acquisition).

At first glance, these results appear to be in conflict, but they are not because absolute retention scores and relative retention scores actually measure different aspects of performance (see Christina & Shea, 1988, for a detailed discussion of this issue). Absolute retention scores measure the *amount of performance retained* after the RI, whereas both relative retention scores measure the *amount of performance lost* relative to acquisition performance. Thus, absolute retention scores and relative retention scores are measuring opposite aspects of retention performance. Once this is understood, it becomes clear from the example that the amount of performance retained (absolute retention score) should increase with increases in the amount of original learning, and the amount of performance lost (relative retention scores) should decrease with increases in the amount of original learning. In other words, the more one practices in acquisition (original learning), the more performance should be

retained and the less it should be lost over the RI. Taken together, these scores convey a similar idea and are therefore not in conflict. They actually provide converging lines of evidence to support the inference that the more one practices in acquisition the more one remembers, or, conversely, the less one forgets over the RI.

Clearly, each of these scores provides information about a particular aspect of retention performance that the other scores are incapable of providing. The keys to the successful use of these and other scores are:

- Knowing what aspect of performance each of the scores reflects
- Having a thorough understanding of the interrelations among the different scores
- Understanding the methodological and measurement problems inherent in each of the scores

Such understanding will lead to more meaningful selection among the scores for a particular study and provide a basis for interpreting the results obtained in various studies that have used different scores to study retention.

Theories of Forgetting

Trace decay, interference, and retrieval are three theories of forgetting that have concerned psychologists for a long time and all three apply to the forgetting of motor learning, which largely depends on the type of movement task that is learned. These theories of forgetting and forgetting as a function of type of movement task are discussed next.

Trace Decay Theory

Trace decay theory holds that forgetting is due to the passage of time.

Trace decay theory proposes that forgetting is due to the passage of time, which causes degeneration of the memory trace, or engram, of the learned capability for producing a movement performance. The passage of time alone, in the absence of any other factors, is sufficient to cause forgetting. For instance, if over several months (retention interval) you do not play golf or practice hitting tee shots with your driver, trace decay theory predicts that you would, to some extent, forget your learned capability for hitting balls as proficiently as you did when you were playing and practicing regularly. Trace decay theory holds that the longer the period of time you do not play or practice, the more the memory trace of the learned capability for driving the golf ball will be eroded and the greater the forgetting. The fundamental experimental design used to study trace decay theory is shown in Table 11.2. Assume that both groups had the same number of acquisition trials in learning and that group I had a shorter RI than group II. If the longer RI causes a greater decrement in performance of movement A for group II when compared to the performance of movement A for group I, then evidence for motor memory trace decay may be claimed.

The pioneering evidence supporting trace decay theory in short-term motor memory was produced in a study by Adams and Dijkstra (1966), who had blindfolded participants perform a linear positioning task. They varied both

Table 11.2
Experimental Design to Study Trace Decay Theory

Acquisition Phase		Retention Phase	
Group	Learn	Retention Interval (RI)	Retention Test
I	Movement A	Period of nonuse (short RI)	Movement A
II	Movement A	Period of nonuse (long RI)	Movement A

the amount of practice (repetitions) in learning and the duration of the RI and reported two main findings. First, absolute error was less on the retention test for groups that had more practice in learning, which was expected. Second, the absolute error rate increased steadily on the retention test as the RI increased up to 80 seconds, and then leveled off over RIs of 80 to 120 seconds, which they interpreted as support for trace decay theory.

Since the Adams and Dijkstra study, additional support for trace decay theory has been found by others (e.g., Adams, Marshall, & Goetz, 1972; Burwitz, 1974). Tests of trace decay theory for long-term motor memory are virtually nonexistent because it is very difficult, if not impossible, to conduct studies in which (a) competing movement responses do not occur during long RIs (e.g., weeks, months, or years) and (b) the only thing operating is the passage of time. However, evidence for trace decay in short-term motor memory suggests that it also could be operating in long-term motor memory.

Interference Theory

Interference theory holds that forgetting is due to competing responses.

Conversely, **interference theory** attributes forgetting to competing movement responses that occur during the RI, not to the passage of time itself. Forgetting may or may not take place over the RI, depending on the nature and frequency of the competing movement responses that intrude. Competing responses experienced or acquired before learning of the criterion response (**proactive interference**) or after its learning (**retroactive interference**) induce the decrement in criterion performance on the retention test that we call forgetting.

An example of proactive interference would be learning an incorrect golf swing *before* learning a correct one (criterion response). The competing movement(s) between the two swings could cause interference with the memory trace of the capability for performing the correct swing and lead to forgetting over the RI. Evidence for this forgetting would be a decrement in performance of the correct swing following a period of no practice or play, which is the RI. The basic experimental design used to study proactive interference is presented in Table 11.3.

If the prior learning of movement B causes inferior retention test performance of movement A for the experimental group when compared to the retention test performance of movement A of the control group, then evidence for proactive interference may be claimed. There is some support for proactive

Table 11.3
Experimental Design to Study Proactive Interference

	Acquisition Phase		Retention Phase	
Group	**Prior Learning**	**Learn**	**Retention Interval (RI)**	**Retention Test**
Experimental	Movement B	Movement A	Period of nonuse (RI same as control group)	Movement A
Control	Nothing	Movement A	Period of nonuse (RI same as experimental group)	Movement A

Table 11.4
Experimental Design to Study Retroactive Interference

	Acquisition Phase		Retention Phase	
Group	**Prior Learning**	**Learn**	**Retention Interval (RI)**	**Retention Test**
Experimental	Movement A	Movement B	Period of nonuse (RI same as control group)	Movement A
Control	Movement A	Nothing	Period of nonuse (RI same as experimental group)	Movement A

interference in short-term motor memory (e.g., Ascoli & Schmidt, 1969; Stelmach, 1969b), but no research evidence was found for it in long-term motor memory. Proactive interference appears to occur in short-term motor memory when there is similarity between the movement to be remembered (movement A) and the interfering movement (movement B). It appears that proactive interference increases as the number of similar movements (B movements) preceding the movement to be remembered (movement A) increases.

An example of retroactive interference would be learning a golf swing change (movement B) *after* the initial golf swing (movement A) was learned. The competing movement(s) between the two swings could cause interference with the memory trace of the capability for performing the initial swing and lead to forgetting. Evidence for such forgetting would be a decrement in performance of the initial golf swing (movement A) on the retention test after a period of no practice or play (RI). The experimental design for retroactive interference is shown in Table 11.4.

If movement B causes a decrement in the performance of movement A on the retention test for the experimental group, relative to the performance of movement A on the retention test for the control group, then evidence for retroactive interference has been found. Movement B may not always

interfere; it can be neutral or even transfer positively to the performance of movement A on the retention test. There is evidence of retroactive interference in short-term motor memory (e.g., Milone, 1971; Patrick, 1971; Pepper & Herman, 1970; Smyth & Pendleton, 1990), but it seems that forgetting effects in long-term motor memory are also a function of the type of motor task or skill (discrete, serial, continuous, or procedural) and the degree of organizational complexity of the task or skill, which will be discussed in more detail on page 346.

Retrieval Theory

Retrieval theory holds that forgetting occurs because the memory trace cannot be found and recalled.

The **retrieval theory** of forgetting has its roots in psychology of verbal learning and memory that could apply to motor forgetting. Retrieval theory holds that the memory trace of the capability for producing a learned movement performance is not forgotten or eroded due to the passage of time or interference from competing movements. The memory trace resides at full strength in memory over the RI, and a recovery operation is required to recall it on the retention test. Failure to retrieve as a theory of motor forgetting says that the memory trace of the capability for producing a learned movement performance exists at full strength, but it cannot be found and so cannot be recalled.

Most of the psychological research of retrieval theory has used a stimulus at recall as a means of arousing forgotten verbal responses to recall (e.g., Bahrick, 1969; Tulving & Pearlstone, 1966; Thomson & Tulving, 1970; Tulving & Thomson, 1973). This method is referred to as *prompting* and the reminder stimulus is called the *prompter.* The study of retrieval using a prompting approach is a relatively new undertaking in psychology and is even newer in motor learning. Thus, there is little basis for choosing among the various explanations of retrieval theory, but three of them appear to have attracted researchers: mental search, generation-recognition, and encoding specificity.

The **mental search explanation** holds that, when the memory trace of the capability for producing a particular movement response needs to be recalled, a search process through a finite set of memory traces begins. Preferably, the finite set of memory traces being searched contains not only memory traces of capabilities for generating movement responses similar to the one that needs to be recalled, but also the memory trace for the particular movement response needed. Very likely, the prompter narrows the set of memory traces and makes the search more efficient. The more effective the prompter, the smaller the set and the more easily the memory trace needed is retrieved.

The **generation-recognition explanation** argues against mental searching as the process by which the memory trace is retrieved. It proposes that the prompter is a stimulus for generating a hierarchy of memory traces from past learning that are close to the memory trace needed; if the needed memory trace is among them, the learner will recognize it and recall it. The **encoding specificity explanation** argues that, for the prompter to be effective, it must be encoded along with the memory trace of the capability to produce the movement response at the time of learning. This explanation emphasizes the importance of encoding at the time of learning, which is intuitively appealing. However, there are some verbal learning results by Bahrick (1969) that are difficult to account for in terms of the encoding specificity explanation because prompters

were present only at the time of recall and were quite effective. Bahrick's findings are best accounted for by the generation-recognition explanation.

Clearly, support can be found in research on verbal memory and forgetting for these three explanations of retrieval. The extent to which these or some other explanation of retrieval of verbal information can account for the retrieval of motor responses has yet to be determined by research.

Which Theory Is Correct?

It would be simple and convenient if one of the three theories of forgetting (trace decay, interference, or retrieval) accounted for all of the circumstances of motor forgetting of which we are aware, and the other two did not. Unfortunately, simplicity and convenience do not prevail. There is evidence for all three theories in the verbal literature, but there is more evidence in the motor literature for trace decay and interference theories than for retrieval theory. However, there also has been less research testing retrieval theory than the other two theories of motor forgetting, so one would expect to find less evidence for retrieval explanations. The situation is further complicated when trying to apply these theories in the motor domain because there has been very little research testing these theories of forgetting in relation to the type of movement task. There is a greater amount of research for these theories over short rather than long retention intervals; and, consequently, the majority of the evidence supporting the theories does so more for short-term than for long-term motor forgetting. It is more difficult and often unrealistic to experimentally control what learners experience over longer retention intervals (e.g., months to years), hence less research has tested the validity of these theories for long-term motor forgetting. Nonetheless, all three theories appear to be viable explanations, and future research will have to determine the extent to which they or some other explanation can account for motor forgetting relative to type of movement task not only in the short term, but in the long term as well.

Factors That Influence Memory Skill

Now that we have described the various changes in how knowledge is represented in memory as a learner progresses through the various stages of skill acquisition, let us consider the factors that are most likely to influence how well a particular skill is retained for later recall. It is possible to identify many of these factors by examining three important components of any learning situation: the characteristics of the movement skill to be learned, the environmental context in which the skill is to be learned, and the learner. The interaction among all of these components significantly influences how well a particular skill is learned. For example, we can expect a young child who is introduced to a new skill in an unfamiliar skill setting to operate very differently from an older child who is familiar with both the skill to be learned and the environment in which it is to be learned. Similarly, we will find that some skills are just inherently easier to remember than others.

Characteristics of the Movement Skill

Continuous movement skills are better retained than are discrete, serial, and procedural skills.

Type of Movement Skill. As indicated earlier (page 344), the type of movement task or skill to be learned has been shown to strongly influence retention. Continuous movement tasks appear to be more resistant to forgetting than are discrete, serial, and procedural movement tasks (e.g., Bell, 1950; Fleishman & Parker, 1962; Meyers, 1967; Ryan, 1965), but much more research is needed on this topic, especially studies that include relatively long retention intervals (e.g., months to years). Continuous tasks require us to respond to sensory information that is presented continuously, such as in a visual tracking task, riding a bicycle, or other repetitive motor task like swimming.

Procedural and serial tasks seem to be the most easily forgotten (for reviews see Christina & Bjork, 1991; Schendel & Hagman, 1991). Procedural tasks consist of a particular sequence of operations executed in the same way each time that the task is performed, such as disassembling and assembling a rifle or changing a tire. The technique of administering cardiopulmonary resuscitation is another example of a procedural skill that is easily forgotten (see highlight, The Skill of Resuscitation). Serial tasks are the same as procedural tasks except that the steps must be performed in rapid succession; they are self-paced in procedural tasks. If we asked someone to assemble and disassemble a rifle as fast as possible, it would become a serial task. The sequence of skills contained within a gymnastics floor exercise routine is another example of a serial task.

Discrete tasks appear to be forgotten more easily than continuous tasks but seem to be better retained than procedural or serial tasks (e.g., Lee & Genovese, 1988, 1989; Lersten, 1969; Neumann & Ammons, 1957; Shea, Lai, Black, & Park, 2000). Discrete tasks are characterized by having a clearly defined beginning and end such as responding to a signal by pressing the appropriate button or serving a volleyball after a whistle is blown by the referee. Although there are a number of investigations that have studied the forgetting of discrete motor tasks after relatively short RIs (e.g., minutes to days), very few have studied forgetting of discrete motor tasks after relatively long retention intervals (e.g., months to years).

Degree of Task Organizational Complexity. Several hypotheses have been offered to explain why forgetting seems to be a function of task type. Some have argued that discrete and procedural/serial tasks are easily forgotten because they have a considerable verbal-cognitive component, which appears to be more difficult to retain over time than a motor component for a task (e.g., Adams, 1987). Also, some have proposed that continuous tasks are more readily retained because the inherent repetitive nature involved in performing them leads them to be more easily over-practiced and over-learned than discrete tasks. For instance, a practice trial for a discrete task might involve pressing the correct lever when the appropriate signal is heard, whereas a practice trial for a continuous task such as swimming might involve swimming one or more lengths of a pool.

Clearly, much more practice and repetition of the movements that make up the continuous task (swimming) are experienced than in the discrete task. Some scholars (e.g., Adams, 1967) have argued that retention differences as a

HIGHLIGHT

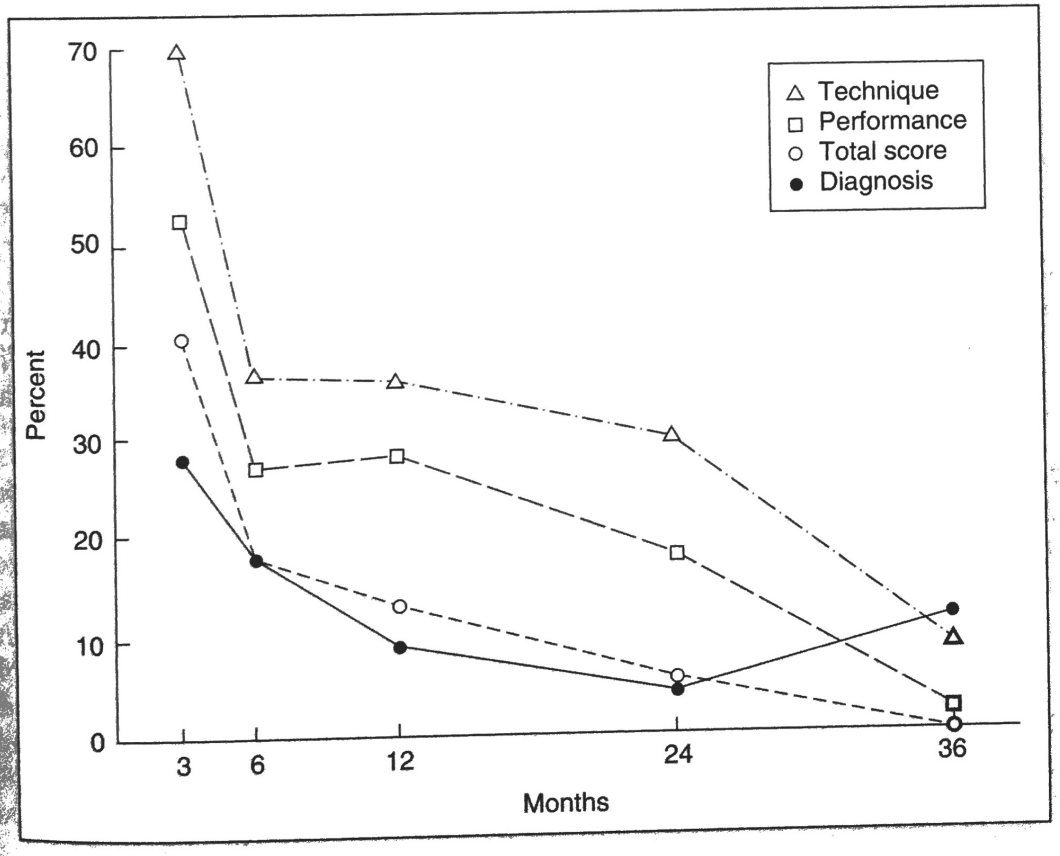
The Skill of Resuscitation

Have you ever wondered why you are required to renew your cardiopulmonary resuscitation (CPR) certificate every one to two years? The reason lies in the inherent organization and cohesion of the skill itself, which consists of a number of operations that must be carefully timed if the technique is to be administered correctly. Although cardiopulmonary resuscitation has been shown to enhance by as much as 40% a person's chances of surviving a serious accident, skill in CPR is difficult to retain for a long period of time.

In order to determine just how quickly the technique is forgotten, Glendon, McKenna, Blaylock, and Hunt (1985) tested a group of individuals who had successfully mastered the resuscitation skill and received their certificate of mastery some three months earlier. Four aspects of their performance were measured:

1. The *performance* and timing of the heart compression component
2. The *technique* used to inflate the lungs and depress the chest in the correct area
3. The quality of the initial *diagnosis* in which the level of consciousness, breathing, and pulse were checked
4. The outcome of the performance as measured by a *total score* representing the predicted survival rate of the patient

As the graph below indicates, the likelihood that Resusci® Annie, the mannequin used to teach resuscitation skills, will survive drops within a year from a level of 100% immediately following training to a low of 15%. After 36 months, the likelihood of survival is zero. It is clear that regular practice in administering this technique is critical if the skill is to be retained. When was the last time you renewed your own certification?



Techniques associated with CPR are quickly forgotten in the 36 months following certification.

function of task type are the result of the way trials and errors are scored. For instance, procedural and discrete motor tasks may be "relatively more sensitive to slight performance deviations than methods used to score the retention of continuous responses" (Schendel & Hagman, 1991, p. 58).

Movement skills that are more inherently organized and meaningful tend to be retained better.

A third hypothesis holds that continuous tasks may be more *inherently organized* (coherent and integrated) than discrete motor tasks (Prophet, 1976; Van Dusen & Schlosberg, 1948), making them more meaningful to the learner. A number of scholars have hypothesized that the more meaningful the task, the more it enables the learner to use principles and relationships from past experiences to help store and retrieve the capability for producing the continuous task performance (Naylor & Briggs, 1961; Schmidt, 1972; Stelmach, 1974).

Among the criteria for determining organizational complexity for procedural tasks or skills are (a) the number of steps involved, (b) whether the order of the sequence can be varied in any way, (c) the extent of planning required to perform the skill, and (d) the degree to which one operation or part of the skill cues the next part. Prophet (1976) has shown that the procedures involved in piloting a plane are particularly susceptible to forgetting, especially when pilots are required to fly a plane using instruments only. The inherent *lack* of internal organization associated with piloting skills has been offered as the primary reason for the poor recall. It has also been suggested that continuous skills are much easier to over-learn because it is impossible to determine when one trial of the skill ends and the next begins (Schendel, Shields, & Katz, 1978). Considerably larger amounts of practice are therefore possible in any given practice session.

Regardless of the type of task, it appears that the degree of organizational complexity, whether inherent in the movement skill or imposed by the learner, is a major determinant of the level of original learning achieved and the amount retained long term (Annett, 1979; Gardlin & Sitterly, 1972; Hagman & Rose, 1983; Hurlock & Montague, 1982; Naylor & Briggs, 1961; Prophet, 1976). Unfortunately, there is no satisfactory way of operationally defining organizational complexity, which makes this factor somewhat difficult to study scientifically. In spite of this limitation, Annett (1979) proposed that variations in the organizational complexity of a task might be conceptualized as being equivalent to variations of task difficulty. As such, to learn a more difficult task successfully, its components may have to be intensively processed, which could lead to an increase in the level of over-learning and thereby promote retention.

Movement Location. Movements can have many features such as velocity, distance moved, force produced, duration, timing, and spatial locations or positions that have the potential to be stored in memory: For instance, movement skills such as a golf swing, tennis serve, basketball shot, and baseball swing have all of these features. The question central to memory is, are some of these features more easily remembered than others? Based on the available basic research, it appears that movement location is remembered quite well relative to the other features (e.g., Diewert, 1975; Diewert & Roy, 1978; Hagman, 1978; Laabs, 1973). Much of this research has been done using simple limb position movements in which participants are blindfolded and found that movement endpoint location is remembered better than movement distance. When participants cannot rely on movement endpoint location and have only

distance cues available, they tend to use a cognitive strategy (e.g., counting) to remember the target movement distance rather than some kinesthetic approach. This finding has been demonstrated in people older than nine years of age (Thomas, Thomas, Lee, Testerman, & Ashy, 1983).

Movement endpoint location tends to be remembered quite well, especially within a person's own body space.

It also appears that movement information about endpoint location is better remembered when it is within the participant's own body space (e.g., Chieffi, Allport, & Woodfin, 1999; Larish & Stelmach, 1982). Typically, people remember a target movement distance by associating the end location of the movement with one of their body parts. For instance, I moved my right hand and arm across my body from opposite my right shoulder to a position opposite my nose. Participants also seem to relate endpoint location of movements to external objects such as a clock face to help them remember. For example, I will move the golf club back to three o'clock and forward to nine o'clock for this short shot. Thus, the implication for teaching and learning is that if you want someone to learn a movement skill involving limb positions, instructional emphasis should be placed on these positions, especially the endpoints of each position to be learned.

Movements that are more meaningful tend to be better remembered.

Meaningfulness of the Movement. Some movements are more meaningful to a learner than others, and the ones that are more meaningful tend to be better remembered (e.g., Laugier & Cadpoli, 1996). For example, a movement skill or pattern that can be related to a previously learned skill or pattern is more meaningful to learn than a skill that does not resemble anything the learner has in memory. For instance, when teaching a tennis serve we might tell and show the learner how many elements of the tennis serve are like many elements of the overhand throw in baseball or softball, which was previously learned. Or when teaching a new defensive play in basketball, we might explain and show how it is similar to the defensive play that was previously learned in soccer. The "switching" strategy in man-to-man defense wherein two defensive players switch and guard each other's offensive player would be an example. Thus, it appears that the more meaningful the skill and patterns are, the better the chance that they will be remembered.

The degree of task organization also could contribute to the meaningfulness of a movement task. For instance, it has been proposed that continuous movement tasks are more resistant to forgetting because they are more inherently organized (coherent and integrated) than discrete tasks (Prophet, 1976), making them more meaningful to learners. Perhaps the more meaningful the task, the more it enables learners to use relevant past experiences in memory to help store and retrieve the capability for producing continuous movement task performance. Clearly, more research is needed before the validity of this explanation can be ascertained.

The beginning and end of a series of movements tend to be recalled better than those in the middle.

Length of a Series of Movements. When the length of a series of movements is greater than five movements, as it is in many procedural tasks (e.g., steps in changing a flat tire or shutting down a nuclear power plant), movements at the beginning and end of the series tend to be recalled better than movements in the middle (e.g., Craik, 1970; Magill & Dowell, 1977; Wrisberg, 1975; Wrisberg & Gerard, 1977). Traditionally, this finding has been referred to as the **primacy-recency effect.** It has been consistently obtained in the verbal research literature and to some extent in the motor skills literature with blindfolded participants trying to recall a series of linear positioning movements.

The amount of research validating this finding for real-world movement skills such as those found in sport or everyday life is also somewhat limited. Nonetheless, to facilitate retention it would be advisable for teachers or coaches to place more emphasis on the movements in the middle of serial routines such as those found in dance, synchronized swimming, or gymnastics. Furthermore, the routine may have to be broken down into smaller segments, with individual practice on these segments. Care should be taken not to overload the learner's memory span, however, which appears to have a limit of about eight movements, when dividing a whole routine into a series of components.

The Level of Original Learning

A number of authors interested in the long-term retention of tasks (Annett, 1979; Hurlock & Montague, 1982; Prophet, 1976; Schendel, Shields, & Katz, 1978) strongly argue that how well a particular task is learned during original learning constitutes the most potent variable determining whether a skill is forgotten over time. This conclusion is echoed in the writings of Christina and Bjork (1991), who, in addition to providing a comprehensive review of the related literature, also discuss a number of strategies designed to optimize the level of original learning and thereby positively influence retention.

The level of original learning for a task is the best single predictor of its long-term retention.

The level of original learning is believed to be completed when a predetermined criterion of mastery has been reached. For example, a baseball coach might regard mastery of the skill of bunting as having been achieved when a player is able to bunt successfully on eight of every ten attempts. How automatically a learner is able to perform a particular skill has also been used as an indicator of learning. One very important way of determining the degree to which a skill has become automatic is to introduce a second skill and observe whether the learner has a sufficient reserve of attention to allocate to performance of the second skill while continuing to perform the first. How well the learner performs the two skills concurrently is a measure of the degree to which the primary skill has been learned.

The Learner

Ability level and past experiences affect how well a skill is remembered.

An instructor has only to watch a class of students trying to recall a motor skill presented in a previous class to see that certain students are better able to recall the skill than are their classmates. Despite the fact that the instructor gave the same verbal instructions, demonstrated the skill in the same way, and provided the same amount of practice opportunities to everyone, some students are simply better able to recall the information necessary for performing the skill accurately. Why do these individual differences exist? More often than not, the ability level and past experiences of the learner affect how well a particular skill is remembered. Farr (1987) suggests that these characteristics of learners "have equipped them with a larger and more varied repertoire of memory-enhancing strategies" (p. 95).

The existence of a greater repertoire of memory strategies can therefore be expected to not only influence how long information can be retained, but also how quickly it can be retrieved from memory at the appropriate time (see highlight, The Structure of Skilled Memory). These memory differences

HIGHLIGHT

The Structure of Skilled Memory

How is it that certain people are capable of memorizing entire books, the days of the week associated with dates several thousand years ago, or the entire multiplication table for numbers between 1 and 100? Some researchers have been so fascinated by the abilities of these individuals that they have spent many years attempting to discover the underlying structure of what they refer to as skilled memory. Ericsson and Polson (1984), for example, studied J.C., a waiter who could memorize as many as 20 complete dinner orders. How was he able to accomplish this impressive feat? A review of the detailed observation notes compiled by these authors over a two-year study period reveals just how J.C. was able to remember such a large amount of information.

Instead of trying to recall each individual order in sequence, J.C. categorized the information into salad dressings that were encoded as a list of first letters corresponding to their names. For example if bleu cheese, oil and vinegar, oil and vinegar, and thousand island dressings were ordered by the first four members of the party, they were remembered as the word BOOT. In order to remember those items that were to accompany the entrée, J.C. used a different mnemonic strategy that involved encoding the food items into patterns (e.g., baked potato, rice, rice, baked potato = abba). Meat temperatures were encoded by first spatially associating them with a linear increase from rare to well-done and then expressing them with numbers from 1 to 4. J.C. finally associated each of the entrées ordered with the position of the person who was ordering it. What is perhaps most interesting about J.C.'s memory ability is that it was not limited to the recall of dinner orders. When asked to recall a new category of items, such as time intervals ranging from 1 second to 1 week, J.C. exhibited the same level of recall within two practice sessions. Apparently, the retrieval strategies he had developed for use in one situation were readily transferable to another.

The study of J.C. and many other skilled mnemonists led Chase and Ericsson (1982) to propose a theory of skilled memory that is predicated on three important principles: meaningful encoding, retrieval structure, and speed-up of memorization. They persuasively argue that individuals with skilled memory not only are capable of rapidly storing information in long-term memory (LTM) and then associating it with existing knowledge in a more meaningful way, but also can retrieve the information using a special set of retrieval cues that are explicitly associated with the information presented. The speed-up of memorization is a function of practice and can lead to storage rates in LTM that are equal to those of short-term memory (STM). The fact that the average individual can be trained to improve his or her memory skill significantly is an especially promising aspect of the theory.

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were highlighted in a study conducted by Anderson and Reder (1979), who were able to distinguish between individuals who could recall historical facts well and those who could not. Those individuals with the better memory strategies were able to elaborate the information far beyond the content presented to them in a fictitious history passage during a free-recall test.

Although the instructor has little control over the abilities and past experiences an individual brings to a learning situation, it is important that individual differences be considered when designing the curriculum and instructing the class. It is clear that instructor-dominated approaches do little to capitalize on the strengths of the learner. In contrast, programs that

emphasize self-paced learning or that place the responsibility for learning squarely in the hands and minds of the learner foster superior learning and long-term retention of skill-related knowledge.

Disorders of Memory

Disorders of memory can result in anterograde and retrograde amnesia.

Disorders of memory may result from cerebral traumas that are either acute in nature (e.g., head trauma, hypoxia or ischemia, and transient global amnesia) or more gradual in onset (e.g., alcoholic amnestic (Korsakoff's) syndrome, brain tumor, and viral encephalitis). Selective memory loss is also observed: Some patients are unable to recall recent memories (**anterograde amnesia**), and others have difficulty retrieving more remote memories (**retrograde amnesia**). In some cases, these disruptions to memory are temporary; in others, they may be much longer lasting. In either case, the rehabilitation process is negatively affected. For example, recovering stroke patients are often unable to remember a set of instructions given as little as 30 seconds earlier even though they remain able to remember the minute details of events experienced some 30 years before. On some occasions, patients recall only a few bits of information from a series of commands, making it almost impossible for them to perform the activity correctly. The generalization of information is also problematic for these patients. It is most often observed when they are asked to perform an activity learned in one setting in a different setting. For example, a patient may learn to transfer from a hospital bed to a chair but may be unable to perform the same set of movements in the home. This inability to apply what has been learned in a practice situation to similar situations arising in daily life significantly slows the patient's return to independent functioning.

Mills (1988) provides a number of strategies for improving the memory of patients involved in a rehabilitation program. When a skill is first being presented to a recovering patient, for example, it is important to keep to a minimum any verbal descriptions and instructions related to how the task is to be performed. By this means, the therapist minimizes the confusion that can result from the overloading of working memory. One might even dispense with verbal instructions when introducing a skill, particularly when working with patients who have experienced damage to the right hemisphere following a stroke. Because these patients have difficulty remembering language, visual demonstrations may prove much more effective than verbal descriptions in conveying how best to perform a particular skill or exercise.

When verbal instructions *are* used to present a skill, the speed with which they are delivered should be carefully controlled. Speaking slowly and clearly will do much to enhance the amount of information understood. How effective the instructor has been in providing verbal instructions will soon be evident in the patient's or learner's response. The nature of the response should therefore be carefully monitored; where confusion is evident, subsequent instructions or demonstrations should be modified.

Self-paced practice should be encouraged so that the patient has adequate time to process the presented information and translate it into action.

Once the skill to be learned has been introduced, it is important that the patient be provided with an immediate opportunity to practice. Active rehearsal boosts the likelihood that the information will be transferred to long-term memory. Self-paced practice should also be encouraged so that the patient

has enough time to process the information presented and then translate it into action. Imposing time constraints on action denies the patient sufficient time to rehearse and organize the information in a manner that is optimal for later retrieval and translation into action. Various part-task training methods are also useful for individuals with memory disorders or as-yet-undeveloped memory functions. These practice methods were discussed in greater depth in Chapter 9. The "Keep It Simple (KIS)" principle certainly should not be overlooked in these types of learning situations.

Mnemonic strategies and devices can enhance the learning process. These are most often provided in the form of verbal cues that the instructor uses to supplement a demonstration of the skill and highlight the important aspects of the task. These cues can then be repeated by the instructor as the learner practices the skill and can even be repeated by the learner as she or he prepares to practice. Encouraging learners to engage in self-talk, or verbal rehearsal, while they practice has been shown to increase how well a particular skill is recalled at a later time (Weiss, 1983; Weiss & Klint, 1987). This instructional technique was discussed further in Chapter 8. Mnemonic devices in the form of memory boards and logs are also frequently used in clinical facilities to help a patient remember a set of exercises or simply maintain a schedule. Skill-related cues written on sheets posted at activity stations set up in gymnasiums are also valuable for learners engaged in practicing many different types of skills at once.

Mnemonic strategies and devices can enhance remembering and the learning process.

Summary

One purpose of this chapter is to familiarize the reader with the construct of human memory and the nature of the operations involved in the acquisition, rehearsal, organization, and recall of skill-related information. Memory is generally divided into two components: short-term and long-term memory. Terms used to differentiate the various types of memory include recall, recognition, intentional, nondeclarative (implicit), declarative, and procedural memory. Whatever labels are used, it is the type of memory function that largely differentiates one kind from the other.

Another purpose was to introduce the reader to how memory and forgetting are studied. The storage and retrieval of the learned capability for producing a movement performance is the process of memory. The loss of the ability to store and/or retrieve the information needed for producing a movement performance is the process of forgetting. The durability of the learned changes in movement performance can be demonstrated over time without practice (that is, following a retention interval, or RI) and is referred to as retention. Memory and forgetting are processes that operate within the learner and hence cannot be directly observed and measured. What can be directly observed and measured is a learner's motor performance in acquisition and on a retention test following an RI, which can be used as evidence from which to draw inferences about memory and forgetting of motor learning.

Care must be taken in our experimental design and procedures to control for contaminating effects due to variables (e.g., changes in motivation, inappropriate warm-up, and reminiscence) that could operate during acquisition and over an RI to confound the effects due to learning, memory, and

forgetting, and could seriously limit the inferences that can be made about these processes.

The trace decay, interference, and retrieval theories of memory were discussed. The trace decay theory holds that forgetting is simply due to the passage of time. Interference theory proposes that forgetting is due to competing responses that occur during the RI. Competing responses learned before learning the criterion response (proactive interference) or after learning it (retroactive interference) are the cause of forgetting. Retrieval theory contends that the memory trace of the capability for producing a learned movement performance is not forgotten and that forgetting occurs because the memory trace cannot be found and so it cannot be recalled. Retention also has been found to be a function of the type of movement skill. Continuous tasks are more resistant to forgetting than are discrete, serial, and procedural tasks, but much more research is needed, especially studies on long-term retention. Research also is needed that examines the three theories of forgetting in relation to the type of movement skill to be learned.

Several variables have been demonstrated to influence the learning and retention of verbal and motor skills. They include the level of original learning, the characteristics of the skill to be learned, the nature of the learning conditions, and the inherent abilities and past experiences of the learner. Research in this area has yielded several strategies that are recommended for the teacher and clinician whose goal is to optimize the learning and long-term retention of cognitive and motor skills. Integral to all of these strategies is the idea that the learner must be actively involved in the learning process.

Important Terminology

After completing this chapter, readers should be familiar with the following terms and concepts.

absolute retention score
anterograde amnesia
consolidation theory
declarative knowledge
declarative (explicit) memory
difference score
encoding specificity explanation
equipotentiality
explicit retention test
forgetting
forgetting hypothesis
generation-recognition explanation
implicit learning
implicit retention test
incidental memory
intentional memory
interference theory
knowledge compilation
levels-of-processing framework
long-term memory (LTM)
memory
mental search explanation
mnemonic strategies
multistore model of stages of memory consolidation
nondeclarative (implicit) memory
percent relative retention score
primacy-recency effect
proactive interference
procedural knowledge
procedural memory
recall memory
recognition memory
rehearsal
relative retention score
reminiscence
retention
retention interval (RI)

retrieval theory
retroactive interference
retrograde amnesia
savings score
set hypothesis
short-term memory (STM)
short-term sensory stage (STSS)
trace decay theory
warm-up decrement

Suggested Further Reading

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Test Your Understanding

1. Cite the major features of the multistore model of memory. How does this view of memory differ from the levels-of-processing framework proposed by Craik and Lockhart (1972)?
2. What is the memory principle of equipotentiality? What types of measurement were used to provide support for this principle?
3. Identify the areas of the central nervous system that have been shown to play a role in memory.
4. Briefly describe the condition known as anterograde amnesia.
5. How does declarative memory differ from procedural memory?
6. According to Anderson, how does the role of memory change as a new cognitive skill is acquired?
7. Cite three factors that have been shown to influence how well a skill is retained for later recall.
8. Differentiate among the terms *memory, forgetting, retention,* and *learning.*
9. Explain the theories of forgetting, including warm-up decrement, and provide an example of how each works.
10. Prepare an experimental design and procedures to study the retention of motor learning, proactive interference, and retroactive interference.

11. Provide numerical examples of how the following retention measures are calculated: absolute retention score, savings score, difference score, and percent relative retention score. Also, explain what each score is measuring.
12. Identify several variables that can contaminate temporary performance effects with the performance effects due to the retention (memory or forgetting) of motor learning, and explain how this contamination occurs and how to control for it.
13. Give movement examples of the following terms: *recall memory, recognition memory, implicit learning, implicit retention, explicit retention,* and *reminiscence.*