CHAPTER 14

RETENTION AND TRANSFER

At one point in the process of revising this text, the two authors got together to discuss some ideas over a long bike ride on the beach in Venice, California. Although the second author had not ridden a bike in many years and, indeed, had never ridden this particular bike before, he managed to avoid causing any serious harm to the sunbathers and volleyball players gathered on the beach that warm spring day. Should we be surprised that the skill of bike riding is retained and transferred so easily? And what factors might influence how well we retain and transfer these and other types of motor skills? Such concerns about how well skills are retained over time and how well they transfer to different situations are of both theoretical and practical importance—theoretical because of the need to understand how the motor system is structured so that skills can be produced "on demand," and practical because usually much time and effort have gone into the learning of the skills, and we need to know how such investments can be protected from loss. This chapter is about the empirical relationships and principles concerned with *retention* and *transfer.*

Fundamental Distinctions and Definitions

You may have the impression that motor learning and motor memory are two different aspects of the same problem, one having to do with gains in skill, the other with maintenance of skill. This is so because psychologists and others tend to use the metaphor of memory as a *place* where information is stored, such as a computer hard drive or a library. Statements like "I have a good memory for names and dates," or "The subject placed the phone number in long-term memory," are representative of this use of the term. The implication is that some set of processes has led to the acquisition of the materials, and now some other set of processes is responsible for keeping them "in" memory.

Memory

A common meaning of the term *motor memory* is "the persistence of the acquired capability for performance." In this sense, habit and memory are conceptually similar. Remember, the usual test for learning of a task concerns how well the individual can perform the skill on a retention or transfer test. That is, a skill has been learned if and only if it can be retained "relatively permanently" (see chapter 10). If you can still perform a skill after not having practiced it for a year (or even for a day or just a few minutes), then you have a memory of the skill. In this sense, memory is the *capability* for performance, not a location where that capability is stored. Depending on one's theoretical orientation about motor learning, memory could be a motor program, a reference of correctness, a schema, or an intrinsic coordination pattern (Amazeen, 2002). From this viewpoint, as you can see, learning and memory are just "different sides of the same behavioral coin," as Adams (1976a, p. 223) put it (see also Adams, 1967).

Forgetting

Another term used in this context is *forgetting*. The term is used to indicate the opposite of learning, in that learning refers to the acquisition of the capability for movement whereas forgetting refers to the loss of such capability. It is likely that the processes and principles having to do with gains and losses in the capability for moving will be different, but the terms refer to the different directions of the change in this capability. "Forgetting" is a term that has to do with theoretical constructs, just as "learning" does. Memory is a construct, and forgetting is the loss of memory; so forgetting is a concept at a theoretical, rather than a behavioral, level of thinking.

As shown in table 14.1, the analogy to the study of learning is a close one. At the theoretical level, learning is a gain in the capability for skilled action, while forgetting is the loss of same. On the behavioral level, learning is evidenced by relatively permanent gains in performance, while forgetting is evidenced by relatively permanent losses in performance, or losses in retention. So, if you understand what measures of behavior suggest about learning, then you also understand the same about forgetting.

Retention and Transfer

Retention refers to the persistence or lack of persistence of the *performance*, and is considered at the behavioral level rather than at the theoretical level (table 14.1). It might or might not tell us whether memory has been lost. The test on which decisions about retention are based is called the *retention test*, performed at a period of time after practice trials have ended (the *retention interval*). If performance on the retention test is as proficient as it was immediately after the end of the practice session (or acquisition phase), then we might be inclined to say that no memory loss (no forgetting) has occurred. If performance on the retention test is poor, then we may decide that a memory loss has occurred. However, because the test for memory (the retention test) is a test of *performance*, it is subject to all the variations that cause performances to change in temporary ways—just as in the study of learning. Thus, it could be that performance is poor on the retention test for some temporary reason (fatigue, anxiety), and so one could falsely conclude that a memory loss has occurred. (At this point it might be helpful to review the learning–performance distinction presented in chapter 10.)

For all practical purposes, a retention test and a *transfer test* are very similar. In both cases, the interest is in the persistence of the acquired capability for performance (habit). The two types of tests differ only in that the transfer test has subjects (all or some) switching to different tasks or conditions, whereas the retention test usually involves retesting subjects on the same task or conditions.

TABLE 14.1. The Analogous States of Motor Learning and Motor Forgetting

	Theoretical level	Behavioral level
Motor learning	Acquiring the capability for moving, gains in memory	Relatively permanent gains in performance with practice
Motor forgetting	Losing the capability for moving, or forgetting, loss of memory	Relatively permanent losses in performance, or retention losses

Measuring Retention and Transfer

Tests of retention and transfer provide indicators about the persistence of an acquired habit during an absence from practice, or about the way in which previous practice influences performance on a new task. Unfortunately, straightforward conclusions from such tests are not always possible. Next, we present the most common and important of the various methods and measures of retention and transfer that have been devised by researchers, and we suggest which ones provide the most useful information.

Retention of Learning

In motor memory research, a number of different measures of retention have been used, and these different methods provide somewhat different interpretations about the underlying forgetting processes. The most common of these methods are *absolute retention* and various measures of *relative retention.*

Absolute Retention

By far the most simple (and scientifically justifiable) measure of retention is absolute retention, defined simply as the level of performance on the initial trial(s) of the retention test. Figure 14.1 shows the hypothetical scores of a group of subjects who practiced the pursuit rotor task (see figure 2.5, p. 32) for 30 trials and then, after a retention interval, performed a retention test involving 30 additional trials. The absolute-retention score is 20, because performance in trial 1 of retention is approximately 20 s of time on target (20 s TOT). Notice that the absolute-retention score is not based in any way on the level of performance attained in the practice trials.

Relative Retention

Various measures of relative retention are possible, such as those using a *difference score* and those using *percentage scores.* These measures express in various ways the absolute-retention score *relative to* scores obtained during the practice trials.

Difference Score Probably the most common relative-retention score is a difference score that supposedly represents the "amount" of loss in skill over the retention interval. It is computed by taking the difference between the performance levels at the end of the practice session and the beginning of the retention test. In the example given in figure 14.1, the difference score is 5 s, as the group performed with a TOT of 25 s before the retention interval and 20 s afterward. Such measures are aesthetically pleasing to many investigators because they seem (erroneously, however) to represent the forgetting processes more or less directly.

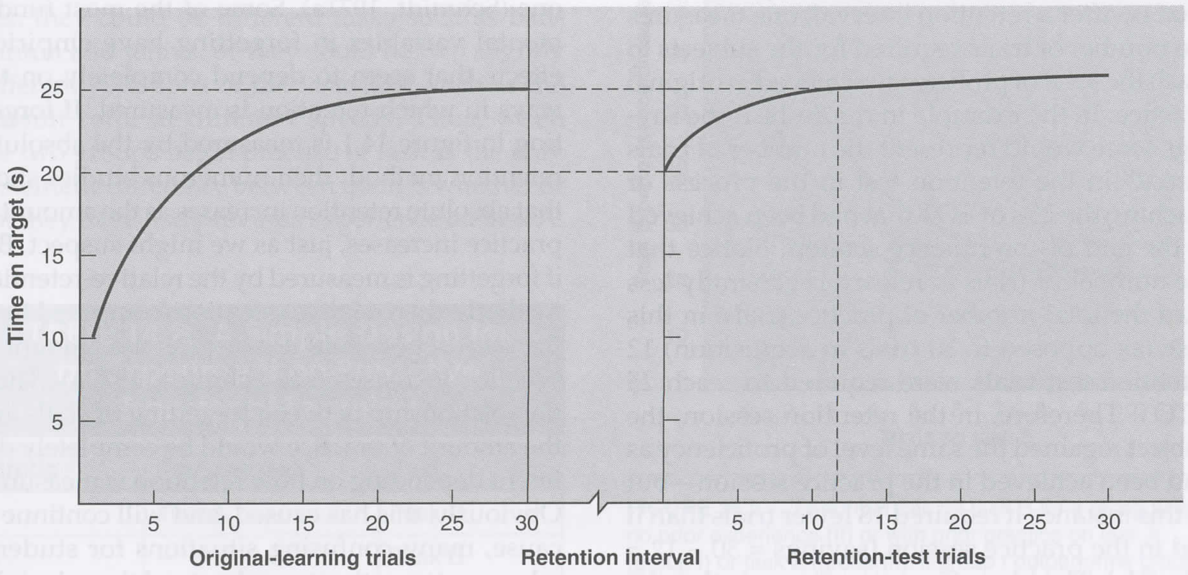

FIGURE 14.1 Hypothetical performance curves on the pursuit rotor for original-learning and retention-test trials.

Percentage Score A second kind of relative-retention score is a percentage score, which represents the "amount" lost in retention over the retention interval relative to the amount of improvement that occurred on the task in the practice session. That is, the percentage score is the difference score (as defined earlier) divided by the amount of change in performance during the practice session (another difference score), then multiplied by 100 for conversion into a percentage. In the example in figure 14.1, the percentage score is the difference score (5 s) divided by the amount of performance change during the practice trials (25 – 10 = 15 s) and multiplied by 100, or 5 / 15 × 100 = 33.3%. The meaning usually given to the percentage score in this case is that one-third of the amount of original improvement during practice was lost over the retention interval. Be careful, though, because such estimates are sensitive to temporary factors that alter performance during practice (e.g., fatigue, random practice) and thus alter the size of the denominator. However, these scores are sometimes useful when one wishes to compare (usually informally) the retention on two different skills, perhaps with different scoring systems.

Savings Score A third measure of retention, which was introduced long ago by Ebbinghaus (1913) and has regained popularity in recent years (e.g., Keisler & Willingham, 2007; Krakauer & Shadmehr, 2006; Seidler & Noll, 2008), involves the "savings" in relearning. That is, after a retention interval, one measures the number of trials required for the subjects to reach the level of proficiency achieved in original practice. In the example in figure 14.1, the savings score would represent the number of trials *"saved"* in the retention test in the process of reaching the 25 s of TOT that had been achieved at the end of the practice session. Notice that the number of trials to relearn is generally less than the total number of practice trials; in this case (as opposed to 30 trials in acquisition) 12 retention-test trials were required to reach 25 s TOT. Therefore, in the retention session, the subject regained the same level of proficiency as had been achieved in the practice session—but in this instance it required 18 fewer trials than it did in the practice session (savings = 30 – 12 = 18 trials). The idea of a savings score is that the more complete the retention, the faster should be the "rate" of relearning, even if the first trial or so show poor performance (due, for example, to warm-up decrement, discussed later).

Contrasting the Various Retention Measures

While it may seem that these various methods merely provide subtle differences in the measurement of a single process (forgetting), this is not the case. According to an analysis of the problem some years ago (Schmidt, 1971a, 1972a), the relative-retention scores are flawed by a variety of factors. The basis of the problem is that all these scores come from *performance* measures, with changes in performance being used to infer something about the changes in the internal state (habit or memory) that underlies performance. Therefore, all the problems with performance curves that we mentioned with respect to the measurement of learning (ceiling and floor effects, for example, in chapter 10) also apply to the measurement of forgetting. In particular, difference scores are subject to a variety of influences that cloud interpretations about forgetting, casting doubt on their usefulness. Moreover, the percentage score is based on two difference scores, one divided by the other to gain the percentage, clouding the issue even further. The savings score suffers a similar problem since the assessment of "savings in relearning" itself employs a difference score in its computation.

The problem is not just a technical or academic one (Schmidt, 1971a). Some of the most fundamental variables in forgetting have empirical effects that seem to depend completely on the ways in which retention is measured. If forgetting in figure 14.1 is measured by the absolute-retention method, then numerous studies show that absolute retention increases as the amount of practice increases, just as we might suspect. But if forgetting is measured by the relative-retention methods, then relative retention (computed from the *same* set of data) *decreases* as the amount of practice increases (see Schmidt, 1972a). Thus, the relationship between forgetting of skills and the amount of practice would be completely different depending on how retention is measured. Obviously, this has caused, and will continue to cause, many confusing situations for students who are attempting to understand the principles of motor forgetting. The absolute-retention score minimizes these problems, and it is the most simple and straightforward one to use.

Transfer of Learning

Transfer is usually defined as the gain (or loss) in the capability for performance in one task as a result of practice or experience on some other task. Thus, we might ask whether practicing a task like badminton would produce benefits or losses (or neither) for another task such as tennis. If it turns out that the performance of tennis is more effective after badminton experience than it would have been with no previous badminton experience, then we would say that the skills acquired in badminton have "transferred to" the skills involved in tennis. It is as if something that is learned in the badminton situation can be carried over to (or applied to) the task of playing tennis (Schmidt & Young, 1987).

Transfer Experiments

Experiments on the transfer of learning can use a variety of experimental designs, but we will not consider them all here (see Ellis, 1965, for a complete description). In the simplest of all designs, assume that there are just two groups of subjects (groups I and II). In table 14.2, group I practices task A for some arbitrary number of practice trials, after which this group is transferred to practice on task B. Group II does *not* practice task A at all, but merely begins practicing task B.

You can think of tasks A and B as any two activities; they could be different tasks such as badminton and tennis, or they could be two slightly different variations of the *same* task, such as the pursuit rotor at different speeds. Thus, when the two groups begin practice of task B, the only systematic difference between them is whether or not they have had previous experience on task A.

TABLE 14.2. A Simple Design for an Experiment on Proactive Transfer of Learning

Group	Transfer task	Test
I	Task A	Task B
II	--	Task B
III	Task Z	Task B

Positive and Negative Transfer Consider the possible results of such an experiment as shown in figure 14.2. Here, the task of interest is task B, so task A performance is not graphed. In figure 14.2, group I, which had task A prior to task B, performs task B more effectively than does group II, which did not have the experience with task A. In this case, we conclude that experience on task A has provided increased capability for task B, equal to 30 units on trial 1 of task B. When the practice on task A enhances subsequent performance on task B, we say that *positive transfer* occurred from task A to task B.

Now consider what happens with another hypothetical group (group III). As seen in table 14.2, group III practices task Z (rather than task A as group I did) prior to trials on task B. In figure 14.2 the performance for group III is less skilled in relation to that of group II by 20 units on trial 1 of task B. For the reasons just mentioned, we conclude that experience on task Z has interfered with group III's capability for performance on task B. In this case, we would say that *negative transfer* occurred from task Z to task B.

Proactive and Retroactive Transfer In the examples given so far, the transfer seemed to

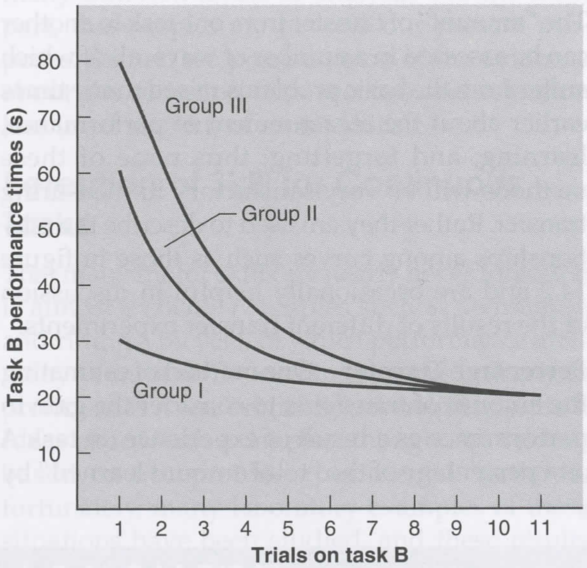

FIGURE 14.2 Performances on task B for a group with no prior experience (II) or with prior practice on task A (group I) or task Z (group III). If group I outperforms group II, then positive transfer has occurred. If group III performs more poorly than group II, negative transfer has occurred.

work "forward" in time from task A or Z to task B. This is termed *proactive* transfer. However, we can also consider *retroactive transfer,* that is, transfer that seems to work "backward" in time. Consider the more complex experimental design shown in table 14.3. Here, two different treatment groups (groups IV and V) both perform task B. Then, group IV performs task Q while group V performs nothing. Later, both groups return to task B for a retention test. If the retention performance on task B is more effective for group IV than for group V, we say that positive retroactive transfer occurred from task Q to task B; practicing task Q seemed to "enhance" the capability already shown on task B. Alternately, if the performance of task B on the retention test is less effective for group IV than for group V, we say that negative retroactive transfer (or interference) occurred; here, practicing task Q seemed to degrade the capability for the previously practiced task B.

The retroactive- and proactive-transfer designs are similar in that they both consider the performance on the *initial* trials of task B in the retention test (or the test phase in table 14.2) to be the critical data indicating transfer. Some measures of these different performances are described in the next sections.

Measurement of Transfer

The "amount" of transfer from one task to another can be assessed in a number of ways, all of which suffer from the basic problems raised many times earlier about the measurement of performance, learning, and forgetting; thus none of these methods will be very satisfactory in measuring transfer. Rather they are used to describe the relationships among curves such as those in figure 14.2 and are occasionally helpful in discussion of the results of different transfer experiments.

Percentage Transfer One method of estimating the amount of transfer is to consider the gain in performance as a result of experience on task A as a percentage of the "total amount learned" by group II in the experiment. The data from groups I and II are illustrated again in figure 14.3. On trial 1 the difference between the two groups is 30 units (labeled as points X and Y). At the end of practice, group II's performance level is 20 units (point C) and has therefore improved by 40 units (60 − 20). The amount of improvement in task B by group II can be represented as the total improvement shown in task B (or $X - C$). Thus, group I's experience with task A has provided 30 out of the possible 40 units of improvement, or 75% transfer. In terms of a more general formula,

$$\text{Percent transfer} = (X - Y) \,/\, (X - C) \times 100 \qquad (14.1)$$

in which $X = 60$, $Y = 30$, and $C = 20$ score units. The formula can also be used for negative transfer as shown in figure 14.2. Here, the values X and C remain the same, but Y (the initial performance level on task B by group III) is larger than it was for group I (i.e., 80). Being careful to keep the signs of the numbers straight, and noting that the numerator of the equation is a negative number

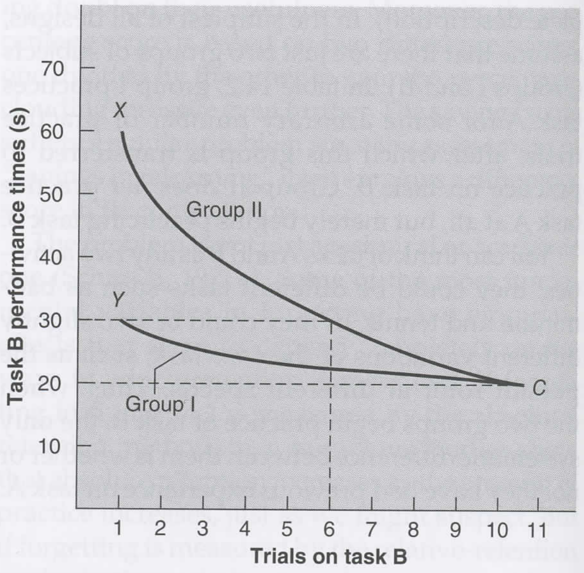

FIGURE 14.3 The calculation of percentage transfer.

TABLE 14.3. A Retroactive Transfer Design

Group	Initial practice	Transfer task	Retention test
IV	Task B	Task Q	Task B
V	Task B	--	Task B

(i.e., *X* – *Y*, or 60 – 80, or –20), we calculate transfer as –20 / 40 3 100 = –50%.

Roughly speaking, we can interpret the percentage transfer as the percentage of gain (or loss) on task B as a result of prior practice on task A. Positive transfer of 100% would imply that the performance on the first trial of task B for group I is at the final level of performance (i.e., point C in figure 14.3) demonstrated by group II. Transfer of 0% would mean that the two groups are the same in initial performance on task B (i.e., both at level *X*).

The reason this measure is inadequate, of course, is that the amount of improvement on task B (i.e., *X* – *C*) will depend on the amount of practice provided, on the scoring system used for task B, on the nature of the subjects, and on countless other arbitrary factors that affect the shapes of performance curves. But using percentage transfer measures can serve a useful purpose in describing the relationships among the curves; just be careful not to take the finding of, say, 75% transfer too literally.

Savings Score Another, far less frequently used method for describing the amount of transfer is a savings score, as already discussed. Here, the savings score represents the amount of practice time "saved" (i.e., reduced) on task B by having first practiced task A. In figure 14.3, group I (which had practiced task A previously) begins its performance of task B at a level of performance equivalent to that shown by group II after six trials. It is possible to say that group I "saved" six trials in the learning of task B by having first learned task A. But this is not the whole story; the "savings" on task B are almost certainly compensated for by a "loss," because task A had to be practiced, and the practice time on task A is usually going to be longer than the amount of time "saved" on task B. That is, for learning task B, usually nothing is as efficient as practicing task B (see chapter 11 for discussion on practice specificity).

Such "savings" begin to have importance when the financial cost of practice is considered. A common example is in learning to fly an airplane, such as the McDonnell Douglas MD-11. To practice in the actual MD-11 aircraft would be very costly, so computer-based simulators that closely resemble the airplane cockpit are frequently used for practice (see figure 14.15, and the related discussion, later in the chapter). Here, the time "spent" in the simulator (task A) is inexpensive relative to the time "saved" in learning to fly the MD-11 (task B), and it is safer as well. In such situations, the effectiveness of a simulator-based training program is often evaluated in terms of financial savings, such savings being the number of hours saved on task B (the MD-11) multiplied by the number of dollars per hour of practice on task B. In the case of the MD-11, dollar amounts of savings can be very large.

Retention and Motor Memory

One of the most frequently studied theoretical issues in psychology—an issue that people often disagree about—concerns memory. Is memory a result of some processing of an event, or does memory refer to the processing *itself*? Are there different types of memory, such as memories for movements, for sensations, for smells, and the like, or is there just one memory, whose *retention characteristics* are a product of the nature and type of processing that is conducted? Questions such as these are hotly debated topics. For example, a scan of the chapters in Byrne (2008) reveals an extremely wide diversity of topics, studied at many different levels of analysis. For the most part, these topics are beyond our present purposes. Rather, we present some of the evidence about the retention (this section) and retention loss (next section) of motor skills.

Retention of Skill for Continuous Tasks

That many motor skills are nearly never forgotten is almost a cliché. Examples such as swimming and riding a bicycle, in which performance after many years of no intervening practice is nearly as proficient as it was originally, are frequently cited. Ideas about such examples, though, are seldom based on acceptable experimental methods; fortunately, many laboratory examples of these situations have been studied, and these results seem to say the same thing.

Although many studies could be cited to illustrate the point, we consider a representative study with long retention intervals by Fleishman and Parker (1962). They used a three-dimensional compensatory tracking task (the Mashburn task, figure 2.5*b*, p. 32), with movements of the hands in forward–backward and left–right dimensions and movement of the feet in a left–right dimension. Subjects practiced in sessions for 17 days, and then separate groups performed retests after either 9, 14, or 24 months.

The scores for practice and retention tests are shown in figure 14.4, where scores for all three retention groups have been averaged together in the practice session. After the different retention intervals, the various groups were nearly equivalent, and none had shown any appreciable losses in proficiency even after two years of layoff. Some tendency was seen for the two-year group to have slightly less proficiency than the groups with shorter retention intervals, but the differences were very small and the losses were regained completely in three sessions. These small differences are not very meaningful when one compares the retention-test performance to the level of performance at the start of practice. Certainly, this continuous task was retained nearly perfectly for two years.

Other studies, using different continuous tasks, have shown very similar effects. Meyers (1967), using the Bachman ladder climb task, demonstrated nearly no loss in performance for retention intervals of up to 12 weeks. Ryan (1962), using the pursuit rotor and stabilometer tasks, found nearly no retention losses after retention intervals of 21 days; later, he found only small losses in performance on the stabilometer task with retention intervals of up to one year (Ryan, 1965). There are many other examples, and the generalization continues to hold. Continuous motor tasks are extremely well retained over very long retention intervals, just as the cliché about the bicycle would have us believe.

Retention of Skill for Discrete Tasks

While there is ample evidence of nearly complete retention of continuous skills, the picture appears to be quite different for discrete skills. Consider an example by Neumann and Ammons (1957). The subject sat in front of a large display with eight pairs of switches arranged in an inside and an outside circle of eight switches each. The subject was to turn the inner switch "on" and then discover which switch in the outer circle was paired with it; a buzzer sounded when the correct match was made. Subjects learned the task to a criterion of two consecutive errorless trials, and then retention intervals of 1 min, 20 min, two days, seven weeks, and one year were imposed for different groups of subjects.

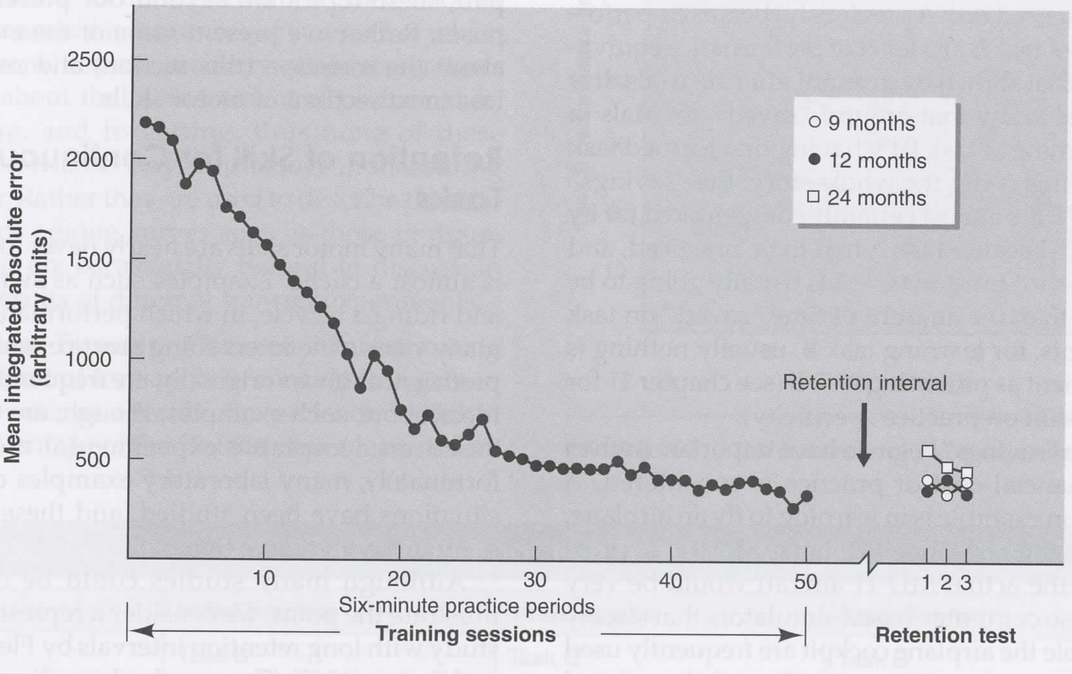

FIGURE 14.4 Mean performance on a three-dimensional tracking task in original learning and after three retention intervals.

Reprinted from E.A. Fleishman and J.F. Parker, 1962, "Factors in the retention and relearning of perceptual motor skill," *Journal of Experimental Psychology* 64: 218.

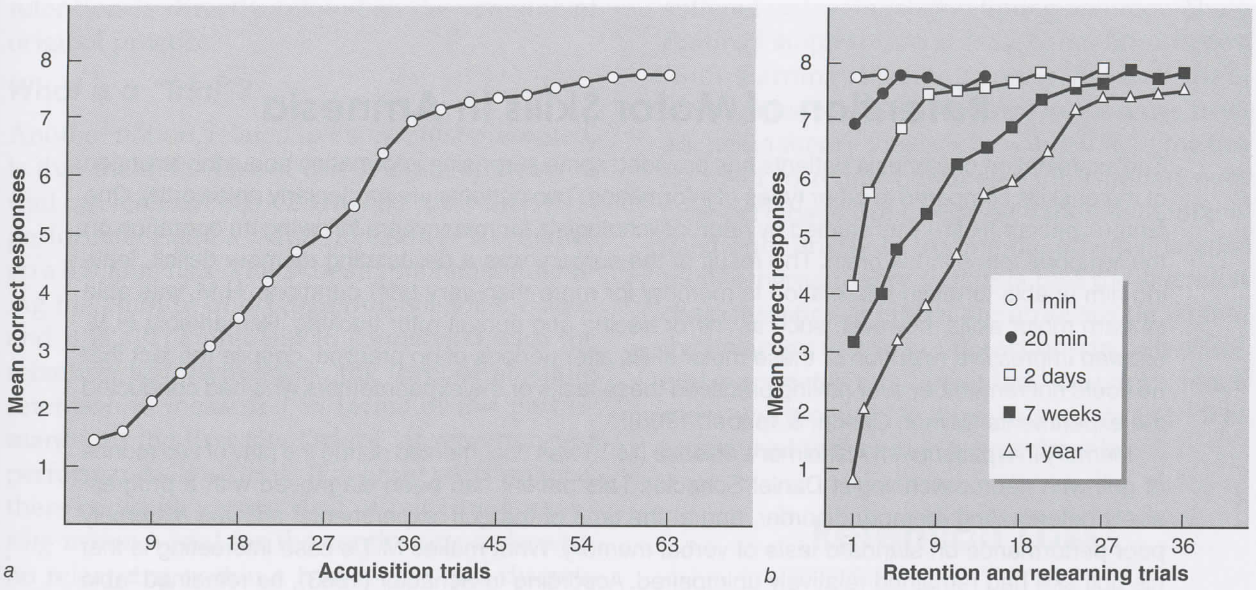

FIGURE 14.5 Mean performance of a discrete task in original learning and after various retention intervals.

Reprinted, by permission, from E. Neumann and R.B. Ammons, 1957, "Acquisition and long term retention of a simple serial perception motor skill," *Journal of Experimental Psychology* 53: 160.

The main findings are presented in figure 14.5. Some losses in performance appeared after only 20 min, and the losses became progressively greater as the length of the retention interval increased. In fact, after one year, the performance was actually less correct than the initial performance in practice had been, suggesting that the forgetting was essentially complete. However, notice that in all cases the improvements during the retention trials were more rapid than in the original-practice session (as indicated by comparing the slopes of the relearning and practice session curves), indicating that some memory for the skill was retained, which facilitated performance in these relearning trials.

Continuous Versus Discrete Tasks

Why is there such a large difference in the retention characteristics of continuous and discrete skills, with continuous tasks having nearly perfect retention and discrete tasks having such poor retention? A number of hypotheses have been proposed to explain these differences, and they are discussed next.

Verbal–Cognitive Components

One hypothesis is that verbal–cognitive components are somehow more quickly forgotten than motor components; because discrete tasks seem to have a heavier emphasis on verbal–cognitive elements (learning which switch in the inner circle is paired with which switch in the outer circle in the Neumann & Ammons study, for example), there is more loss for the discrete tasks over time. Ideas similar to this have generated considerable interest among neuropsychologists who study differences in the retention characteristics of various tasks (e.g., see "Retention of Motor Skills in Amnesia").

However, while it is true that most of the discrete tasks that have been studied in retention situations seem highly verbal-cognitive (e.g., Schendel & Hagman, 1982), there is no reason that discrete tasks must be so. Certainly, one can think of many discrete tasks that have relatively little reliance on verbal–cognitive abilities (e.g., throwing, striking, pole-vaulting). What would be the retention characteristics of a discrete task that was highly "motor" in nature? Lersten (1969) used an arm movement task (the rho task) in which a circular and a linear movement component had to be performed as quickly as possible. He found approximately 80% loss (of the original amount of improvement) in the circular phase, and a 30% loss for the linear component, with retention intervals of one year. Similarly, Martin (1970) used a task in which the subjects moved the hand over two barriers and then returned to

Retention of Motor Skills in Amnesia

The examination of amnesia patients has provided some surprising information about the retention of motor skills compared to other types of information. Two patients are particularly noteworthy. One famous patient (H.M.) was studied by neuropsychologists for many years following an operation on the temporal lobes in his brain. The result of the surgery was a devastating memory deficit, leaving him unable to retain information in memory for more than very brief durations. H.M. was able to learn motor skills, however, such as mirror tracing and pursuit rotor tracking. Remarkably, H.M. showed impressive retention of these motor skills after periods of no practice, despite the fact that he could not remember ever having practiced these tasks or the experimenters who had conducted the experiments (Milner, Corkin, & Teuber, 1968)!

Memory in a patient with Alzheimer's disease (M.T.) was documented during the play of two rounds of golf with neuropsychologist Daniel Schacter. This patient had been diagnosed with a progressively deteriorating memory disorder, and at the time of the golf "experiments" showed extremely poor performance on standard tests of verbal memory. What makes M.T.'s case interesting is that his golf skill had remained relatively unimpaired. According to Schacter (1983), he remained "able to execute a complex set of acquired perceptual-motor procedures in a relatively fluent manner . . . generally hit the ball straight and frequently hit it for respectable distances . . . frequently sank putts up to 5 or 6 feet long, and twice holed putts from over 20 feet" (p. 239). Nevertheless, M.T.'s memory deficits caused frequent problems in playing golf. For example, if M.T. was the second person of the twosome to hit his tee shot and left the teeing area immediately, then he had a good probability of finding his ball. However, if he teed off first, he usually had no idea where the ball had gone and occasionally had forgotten that he had already played his tee shot!

The existence of motor retention for newly acquired learning in people with amnesia (H.M.) and for a previously acquired skill (M.T.) in the presence of severe retention deficits for other types of information is a type of memory *dissociation*. Similar dissociations for preserved retention of motor skill, combined with memory loss for information about the details of the practice session, have since been documented for healthy subjects (e.g., Hikosaka et al., 2002; Verdolini-Marston & Balota, 1994). These dissociations have been explained by some theorists as supporting the view that the retention of (or memory for) motor skills is fundamentally different from the retention of other types of information, such as verbal knowledge (e.g., Roediger, 1990; Schacter, 1987). Various dichotomies have been used to describe this distinction, such as implicit versus explicit memory and declarative versus procedural memory, representing a continuing source of experimental and theoretical curiosity in contemporary research.

a starting switch as quickly as possible, finding approximately 50% retention loss over a four-month retention interval. The large amount of loss in retention for discrete skills that can be considered "mostly motor" is similar to the loss experienced by Neumann and Ammons' subjects (figure 14.5), suggesting that there is more to these effects in retention than just the "motorness" of the tasks.

Amount of Practice

One of the major factors determining absolute retention is the amount of original practice, with retention increasing as the amount of original practice increases. In tracking, for example, there are many instances within a trial lasting 30 s in duration in which the pointer and track become separated, with each instance requiring a separate adjustment. Thus, a single "trial" may require many separate "discrete" actions. Contrast this situation to that for discrete tasks, for which a trial typically consists of a single adjustment or action. It stands to reason, therefore, that with the same number of learning trials, the continuous task receives far more practice than the discrete task. The extra amount of practice, according to this hypothesis, leads to increased retention, since it is well known that absolute retention is directly related to the amount of original practice.

What is a "Trial"?

Another notion, related to the one just presented, is that the definition of *trial* is quite arbitrary; a trial can refer to both a 200 ms reaction-time (RT) performance and a 2 min duration performance on a tracking task. This poses a problem for defining the amount of original practice for the task, and it is also a problem in connection with the retention test. Remember, the level of absolute retention is measured in terms of the performance on the first few "trials" of retention-test performance. If a "trial" is a 2 min performance, there could be a great deal of relearning *occurring within* a trial for the continuous task, with no relearning within a trial for a rapid discrete performance. So the initial movements within the first trial for the continuous task could show considerable retention loss, but the experimenter might not detect it because the error in the initial performance would be "averaged" with the later portions of the trial on which performance was more proficient. Because this could not occur for the discrete task, it is possible that the amount of forgetting is typically underestimated for the continuous task and not for the discrete task, making the two kinds of tasks appear to be different in their retention characteristics when they might otherwise not be. Fleishman and Parker (1962) found a great deal of improvement within a continuous-task trial, as might be suspected.

Retention of Generalized Motor Programs Versus Parameters

Another possible difference in the forgetting of continuous and discrete tasks is that researchers might be examining different characteristics of the task. Evidence of this was found in a study by Swinnen (1988), who had subjects learn an elbow flexion–extension–flexion task with a goal movement time (MT) of 650 ms. Following 60 trials of practice (with knowledge of results, KR), no-KR retention tests were given after intervals from 10 min to five months. Swinnen analyzed separately the retention of absolute timing (related to the movement parameter) and relative timing (related to the generalized motor program, GMP) and found that absolute timing decayed rapidly, supporting much of the research in this area for discrete tasks. In contrast, the GMP information suffered no loss in relative timing accuracy. These findings suggest that at least some information from learning discrete tasks is retained quite well. Moreover, these findings make sense from a schema theory view (Schmidt, 1975b). One has no need to retain parameter information over long periods of time, because that information is used only briefly to update the schema. In contrast, schema theory suggests that the retention characteristics of GMPs are quite strong so that the invariant features of the action can be recalled and parameterized as needed. Certainly, much more work could be done to explore the ideas introduced in Swinnen's experiments.

Retention Loss

In this section we present four different research methods used to investigate retention loss in motor performance, followed by a discussion of related theoretical and experimental issues about the processes through which retention loss occurs. Each method highlights some important features about performance loss that are revealed under different task conditions.

Iconic Memory and Motor Performance

As we discussed in chapter 5, motor performance benefits considerably from the availability of visual information, especially for actions that require precise end-point accuracy, such as manual aiming (e.g., typing; moving a cursor). However, there is considerable evidence to suggest that *continuous* visual information is unnecessary in order to maintain accuracy. The reason is that our memory for the immediate visual environment can "fill in" the gaps if the continuous supply of vision is cut off. For example, suppose you took aim at the bull's-eye in dart throwing and the room lights suddenly went out just before you started moving the dart. How would performance be affected? Research using experiments that closely resemble this situation suggests that performance would depend on the length of time you were in the dark before throwing the dart.

Studies by Elliott and his colleagues suggest that motor performance deteriorates quickly because persistence of the visual information (the icon) fades rapidly from sensory memory

(Sperling, 1960). For example, in a study by Elliott and Madalena (1987), subjects moved a stylus to a target under various conditions of available room light. A control condition provided subjects with continuous visual feedback of the target and stylus. In another condition, the room lights were extinguished as the subjects initiated their movements; thus the entire movement (durations of 200-500 ms) was made in the absence of any direct visual information. The other three conditions also involved movements without visual information available; however, these movements were made after the room lights had been extinguished for 2, 5, or 10 s.

As figure 14.6 shows, subjects could perform the aiming movements well without visual information if the entire movement was *completed* within half a second after the room lights were turned off. Performance was markedly disrupted, however, after a wait in the dark of 2 s or more. Elliott and Madalena (1987) interpreted these findings to suggest that a very short-lived memory for visual information can support performance rather accurately (see chapter 3; reviews by Elliott, 1990, 1992; also Farrell & Thomson, 1998). However, the information is prone to forgetting due to a *decay* of the icon—a process whereby rapid information loss is attributable to the passage of time.

The findings of Elliott and Madalena (1987) and others (e.g., Binsted, Rolheiser, & Chua, 2006) indicate that motor performance can be supported for a brief time by a short-term sensory store, which loses information quite rapidly. These findings suggest a process similar to that proposed in the oldest theory of forgetting, the *trace-decay* theory. It is a passive theory of memory loss caused by disuse—information is forgotten because it is not practiced and therefore "decays" with time. The memory of an item, event, or skill is thought to be represented as a trace in the central nervous system, with the strength of this trace weakening over time. When the information or skill in memory is needed at some future time, performance accuracy is related to the current strength of the trace. This idea accounts well for the common effects of disuse and, of course, for the fact that time, per se, seems to be a strong factor in forgetting.

Considerable research on trace-decay effects in slow, linear-positioning tasks has been conducted using what is called the *short-term motor memory paradigm* (chapter 3). This involves the presentation of a movement, followed by recall of that movement after very brief time intervals, often only a few seconds in duration. These studies used methods that paralleled methods in experiments in memory for verbal materials, early investigations having been conducted by Brown (1958) and Peterson and Peterson (1959). In one of the first motor studies, Adams and Dijkstra (1966) had subjects move to a stop that defined a target position, then return to a starting location for a retention interval, and finally, estimate the defined target position but with the stop removed. Subjects were blindfolded and not given KR about their movement accuracy. In addition, subjects were given various numbers of "reinforcements," whereby movement to the target position was presented 1, 6, or 15 times before the retention interval.

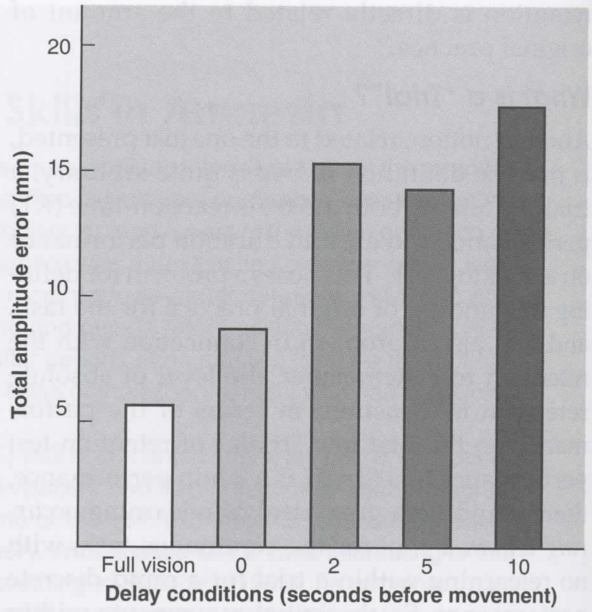

FIGURE 14.6 Total amplitude error in aiming under conditions of vision and without vision under various delay conditions.

Data from Elliott and Madalena 1987.

The major findings are presented in figure 14.7. The absolute errors on the recall trials are presented as a function of the number of "reinforcements" and the length of the retention interval. As the length of the retention interval increased, the error in recall also increased, with the increases being nearly maximized by the time the retention interval was 80 s in length and

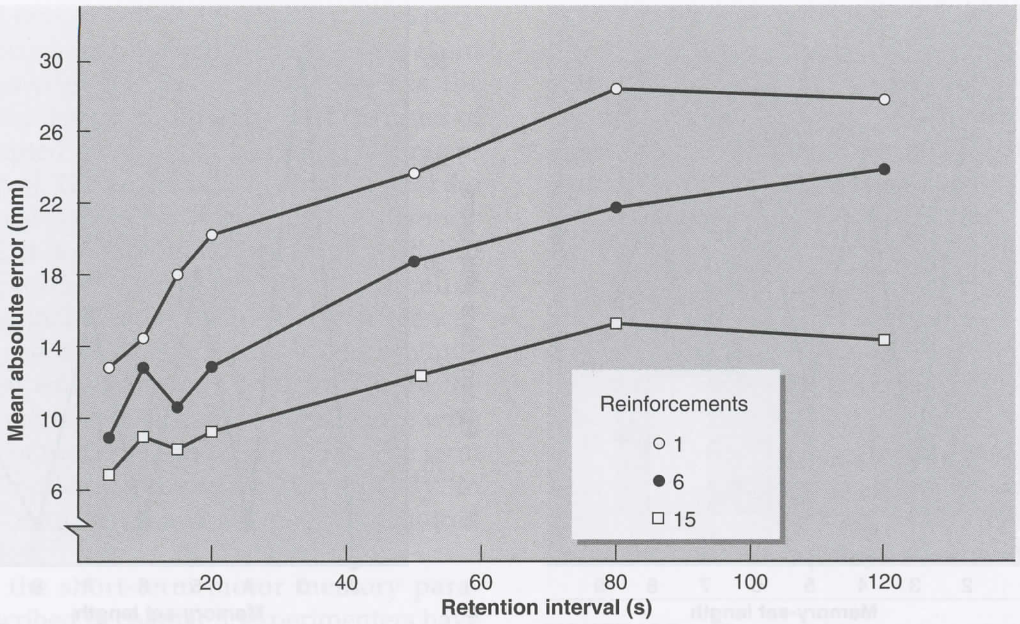

FIGURE 14.7 Mean absolute error in positioning as a function of the retention-interval length and the number of "reinforcements."

Reprinted, by permission, from J.A. Adams and S. Dijkstra, 1966, "Short-term memory and motor responses," *Journal of Experimental Psychology* 71: 317. Copyright © 1966 by the American Psychological Association.

with no important increases thereafter. Similar to memory for verbal items, memory for these linear-positioning movements appears to have a forgetting process that is nearly completed in about 1 min. Also, the rate of forgetting appears to be slowed by "reinforcements," or practice; the errors were systematically smaller with more repetitions of the target position.

One interpretation of these results is that the movement to the stop created a short-term memory representation of the feedback qualities of the correct position. Further, it appeared that, although this representation was weakened over the course of the empty retention interval, it was strengthened by repetition. These factors combined to determine the "strength" of the representation against which the feedback was compared at the retention test—weakened by time, but strengthened by repetitions. It is also possible that forgetting can occur by means other than trace decay. This idea is presented in the next example.

Brief Postmovement Memory

Now consider a very different and clever memory-related paradigm, developed by Rosenbaum and his colleagues (Rosenbaum, Weber, Hazelett, & Hindorff, 1986; see also Rosenbaum, 2009). The subject's task is easy to simulate: The basic requirement is to speak aloud as many letters as possible in 10 s, alternating between a loud voice and a soft voice with each spoken letter. For example, in one condition the subject would shout the letter *A*, then softly speak the letter *b*, then shout C, softly speak *d*, then start over again by shouting *A*, and so on (*AbCdAbCd* . . .). Notice that a loud vocalization was always required for the letters *A* and *C*, and a soft vocalization was always required for *b* and *d*. And this is true for any *even*-numbered memory set. Now compare this to an *odd*-numbered memory set, such as *AbCaBcAbCaBc*. Notice now that the stress on a specific letter *switches* to the opposite stress on each repeated cycle. This feature is consistent for all *odd*-numbered memory sets.

The speed and error data from Rosenbaum and colleagues' (1986) experiment are presented in figure 14.8. As you would expect, more letters in the even-numbered memory sets (2, 4, 6, 8) were produced in 10 s than in the odd-numbered sets (3, 5, 7, 9) (figure 14.8*a*). Also, trials on which errors occurred were more frequent for the odd-numbered than the even-numbered sets (figure 14.8*b*).

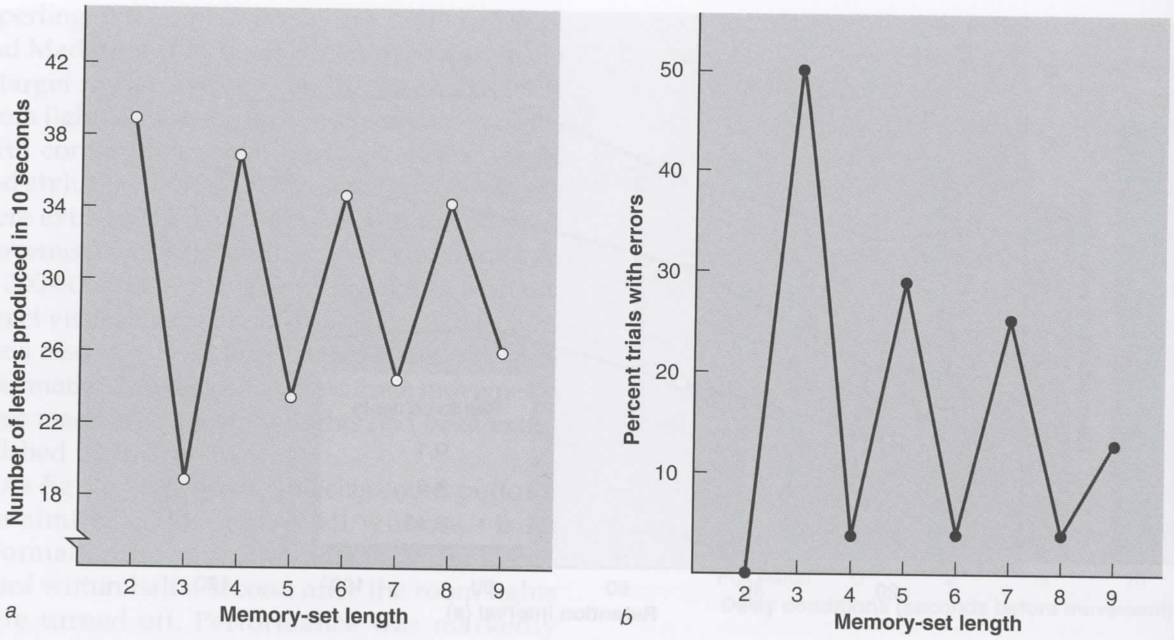

FIGURE 14.8 *(a)* Total number of letters spoken and *(b)* percentage of trials with errors as a function of memory set length.

Adapted from *Journal of Memory and Language*, Vol. 25, D.A. Rosenbaum, R.J. Weber, W.M. Hazelett, and V. Hindorff, "The parameter remapping effect in human performance: Evidence from tongue twisters and finger fumblers," pg. 713, Copyright 1986, with permission of Elsevier.

What do these findings suggest about motor memory? One view is that this task required subjects to vocalize letters (all having different learned GMPs) with different parameterizations—in this case the specific parameter of interest was whether the letter is spoken loudly or softly. Once the letter was produced, the parameter used for that instance was retained in memory. If the next vocalization of that same letter required the same parameter (i.e., as in an even-numbered memory set), the accurate representation that remained in memory *facilitated* performance. However, if the opposite parameter was required (i.e., as in an odd-numbered memory set), the memory of the previous parameter for that letter *interfered* with performance because the remembered parameter needed to be changed. Thus, a strong memory representation either facilitated or degraded performance, depending on the task demands.

But notice something else in the speed and error data in figure 14.8. As the length of the memory set increased, the size of the performance difference between the even- and odd-numbered sets was reduced. The memory-set effect, which previously had either facilitated or degraded performance, was *reduced* when more letters intervened between the repetitions of any one letter. We expect that if the length of the memory sets had been extended even further (e.g., to 25 and 26 letters), the performance differences between the odd- and even-numbered letter strings might have been eliminated completely. This finding suggests a *weakening* of the influence of a previous performance on selecting a parameter for a subsequent performance, which is dependent on the memory-set size.

Two possible influences seem to be occurring in Rosenbaum and colleagues' (1986) study. As the length of the memory set increased, the *time* between any two vocalizations of the same letter increased, resulting in a decay of the representation for the previous parameter. The mere passage of time is not all that happened, though, because as the memory-set size increased, more intervening letters were spoken, which caused more *interference* with the memory for any specific previously spoken letter. Thus, another cause of forgetting may have had something to do with these events, rather than mere passage of time as trace-decay theory would have it.

Interference theory suggests that memory is actively degraded by other events. Such interference, according to the theory, can be of two basic kinds: *proactive interference* and *retroactive interference* (Underwood, 1957). The most common research method involves an experimental paradigm in which the interfering event occurs between the time of the storage of the to-be-remembered information and the time of the attempted recall—that is, during the retention interval. The term *retroactive* implies that the interference "works backward" on the memory; of course, it does not work backward at all, but it does nevertheless serve to disrupt the recall of something that occurred before the interference.[1] Interference can also occur in a less obvious way when something that happens before the criterion memory task causes interference with the recall of that criterion information. The term *proactive* implies that the information already "in memory" interferes with more recently acquired information.

Using the short-term motor memory paradigm described in chapter 3, experimenters have attempted to assess the mechanisms causing forgetting in relation to interference theory. With respect to *proactive interference,* neither Adams and Dijkstra (1966) nor Posner and Konick (1966) found evidence that later positions to be remembered in a sequence were less accurate than earlier ones, which would be expected if the proactive interference from the earlier movements were disrupting the memory of the later positions. Such findings had been shown in verbal behavior. One reason these proactive effects may not have occurred in the motor studies is that the intertrial intervals were very long (2 min in Adams & Dijkstra's study; figure 3.21 on p. 90), possibly providing an opportunity for forgetting of an earlier movement before a later movement could be presented.

Ascoli and Schmidt (1969) studied proactive effects by concentrating the prior movements into a short period of time. They presented either zero, two, or four positions just prior to the presentation of a criterion movement (the movement to be remembered). A retention interval of either 10 or 120 s followed the criterion movement, then recall of the criterion movement was attempted, and finally a recall of the preliminary movements (if any) was done. Figure 14.9 presents absolute errors in recall for the two retention intervals and for the various numbers of prior movements. Errors increased as the length of the retention interval increased. But of more interest was the finding that the four-prior-position condition showed more error than either the zero- or two-prior-position condition. A major effect was seen for constant error, with increased prior positions making the movements systematically too short. The data can be interpreted to mean that proactive interference is a factor in the retention of these positioning movements, supporting the interference theory (see also Stelmach, 1969).

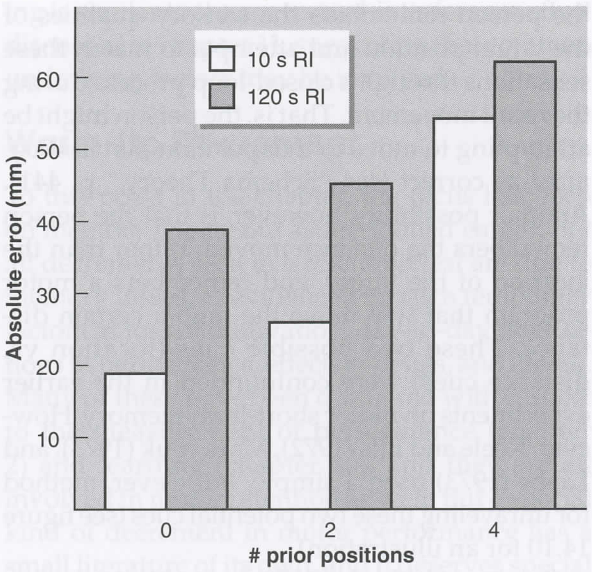

FIGURE 14.9 Mean absolute error in positioning as a function of the retention-interval length and the number of previous positions.

Adapted, by permission, from K.M. Ascoli and R.A. Schmidt, 1969, "Proactive interference in short-term motor retention," *Journal of Motor Behavior* 1: 29-35, adapted with permission of the publisher (Taylor & Francis Ltd, http://www.informaworld, com).

With respect to *retroactive interference,* some earlier researchers failed to find effects of activities placed between the presentation and the recall of the test movements, casting serious doubt on the application of interference theory to memory for movements. But none of these studies reported constant errors, and the finding that proactive interference had its major effects on constant error raised the possibility that retroactive effects would be seen in the same way. In a reanalysis of earlier data, Pepper and Herman (1970) found that movements produced during the retention interval tended to have negative effects on movement accuracy when measured in terms of constant error. Subsequently, Patrick (1971) and Milone (1971) also provided evidence for retroactive interference.

Cue-Separation Techniques

What does the performer remember and recall in these positioning tasks? One possibility is that the person remembers the sensory qualities of the target position and attempts to match these sensations through a closed-loop process during the recall movement. That is, the person might be attempting to move to that position that is *recognized* as correct (see "Schema Theory," p. 441). Another possibility, however, is that the person remembers the distance moved, rather than the location of the target, and remembers a motor program that will move the limb a certain distance. These two possible cues (location vs. distance cues) were confounded in the earlier experiments on motor short-term memory. However, Keele and Ells (1972), Marteniuk (1973), and Laabs (1973) used a simple, but clever, method for unraveling these two potential cues (see figure 14.10 for an illustration).

For example, Laabs (1973) had subjects move to a stop for the presentation of the stimulus materials (as in the Adams & Dijkstra study). Then he formed two different conditions for recall. In both of these conditions, subjects began at a *different* starting position for the recall movement. In one condition, subjects were asked to recall the same *location* on the curvilinear track as before, so the distance of the recall movement was different from that of the presentation movement, rendering memory for distance unreliable. In the other condition, the subject was asked to move the same *distance* as in the presentation movement, so the location of the presentation movement was unreliable to the subject for recall.

Laabs' major findings were that accuracy was far greater in the condition in which the location cue was recalled than in the one in which the distance cue was recalled. Subsequent research has suggested that subjects have a difficult time remembering cues about movement distance and that positioning movements are probably based on some memory of location. However, retroactive-interference effects for location and distance information may occur in complex ways in some instances (Imanaka & Abernethy, 1991, 1992; Imanaka, Abernethy, & Quek, 1998; Walsh, Russell, Imanaka, & James, 1979).

The Preselection Effect

In the usual paradigm for motor short-term memory studies, the subject is asked to move to a stop that is defined by the experimenter; thus the subject does not have any advance knowledge about where the movement end point is located until she contacts the stop. Marteniuk (1973) and Stelmach, Kelso, and Wallace (1975) introduced a new method when they asked subjects to choose their own movement end points. In

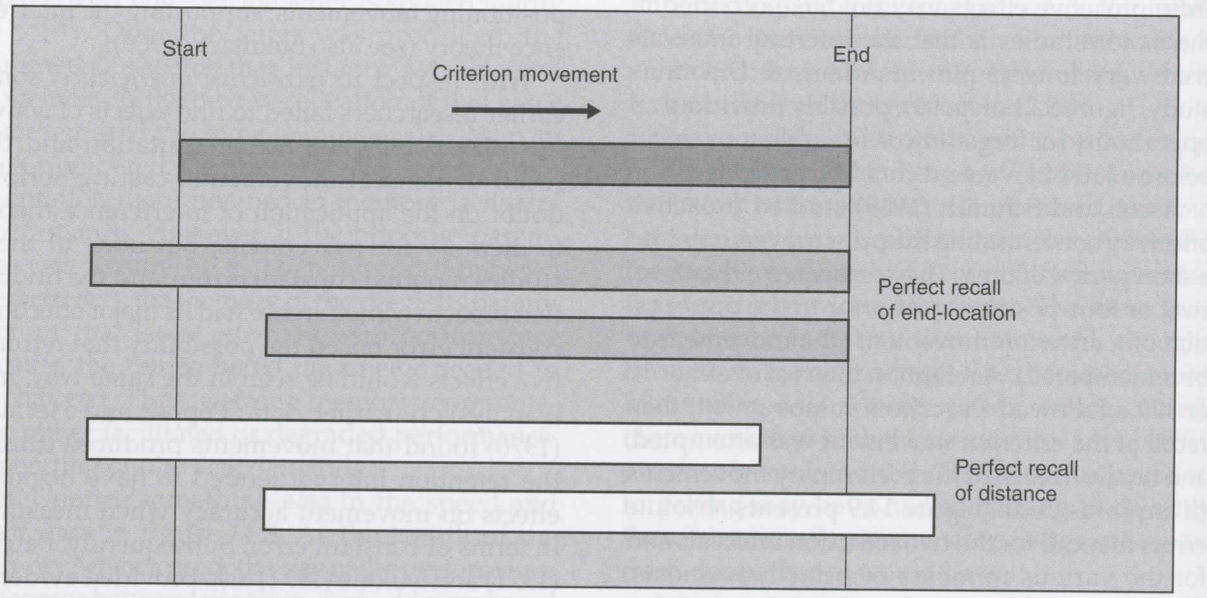

FIGURE 14.10 Illustration of the motor short-term memory paradigm used to separate the effects of end-location and distance cues.

Adapted, by permission, from K. Imanaka, B. Abernethy, and J.J. Quek, 1998, The locus of distance-location interference in movement reproduction: Do we know any more 25 years on? In *Motor behavior and human skill,* edited by J.P. Piek (Champaign, IL: Human Kinetics), 33.

effect, the instruction was to move to a position of the subject's choice (a stop was not provided); then the subject returned to the starting position and was asked to reproduce the position after a retention interval. This so-called *preselection* method led to much more accurate recall than the experimenter-defined method. Note that these findings have some similarity to recently studied effects in learning when subjects are allowed to regulate their own practice schedule (chapter 11) or augmented feedback presentations (chapter 12). The key commonality may be related to the active involvement of the learner in remembering and learning processes.

When the subject is faced with these reproduction situations, it is likely that the nature of the methods will influence the way in which the person stores the information. For example, if the person does not know where the target will be (in the standard paradigm), this could force the individual to process sensory cues about the target location, perhaps leading to a strategy wherein the recall of the movement is produced through closed-loop processes. In the preselection method, however, the performer can generate a movement plan in advance, perhaps programming it, and thus can ignore the sensory consequences of the movement—simply rerunning the program at the retention test. This may also suggest that memory for programs or parameterizations may be more stable than memory about the feedback for correct locations.

Spacing of Repetitions

Earlier we presented the findings of the Adams and Dijkstra (1966) study, in which many repetitions of the movement reduced the loss of information during the retention interval. These findings have been replicated often (reviewed in Lee & Weeks, 1987), suggesting that a memory representation is stronger or more resistant to forgetting with "practice." A curious finding, however, is that the repetition effect is enhanced if the repetitions themselves do not occur immediately but instead are spaced apart—especially so if some interference occurs between these repetitions (e.g., Lee & Weeks, 1987; Weeks, Reeve, Dornier, & Fober, 1991). One explanation for this *spacing effect* is that the forgetting that occurs between repetitions actually serves to *enhance* memory on the retention test (see p. 379, "When Forgetting Improves Remembering"). This finding is similar to the contextual-interference effect discussed in chapter 11, suggesting that common underlying factors may be involved.

Warm-Up Decrement

To this point in the chapter, the focus has been on memory losses. But as mentioned earlier, not all decrements seen in a retention test are due to memory losses, as evidenced by such temporary factors as loss of motivation, day-to-day fluctuations in performance, effects of drugs, and illness. Many of these have been discussed with respect to the measurement of performance (chapter 2) and learning (chapter 10), and they are all involved in motor retention as well. But a special kind of decrement in motor performance has a small literature of its own, and it deserves special mention. This effect is called *warm-up decrement.*

The phenomenon can be easily introduced with an example. Adams (1952, 1961) studied a large group of subjects on the pursuit rotor task, providing thirty-six 30 s trials per day for five days; the results are shown in figure 14.11. The typical improvement with practice during a session of trials is seen, but also seen is a relatively large decrement in performance after each 24 h rest period. This decrement appears to be quite severe, and it is equivalent in size to the gains experienced in 5 to 10 trials. It is also rather short-lived, being eliminated in only a few practice trials. The phenomenon has been known for a long time and has been found in nearly every motor task that has been studied (see Adams, 1961, for a review). This decrement was thought to be related in some way to the need to "warm up" (probably not in the usual sense of warming up the muscles) for the task again after the rest, and the phenomenon came to be called *warm-up decrement.* It can be of potential importance when people are asked to perform after a rest period, as occurs with the worker operating a dangerous machine after a coffee break, the athlete going into the game from the bench, or a surgeon's first operation of the day (Kahol, Satava, Ferrara, & Smith, 2009).

Two major classes of explanation for warm-up decrement can be described. A *forgetting hypothesis* holds that the loss in skill is due to forgetting of the type mentioned in the previous sections. On the other hand, various versions of the *set hypothesis* argue that the loss in skill is due to a relatively temporary loss of bodily adjustments

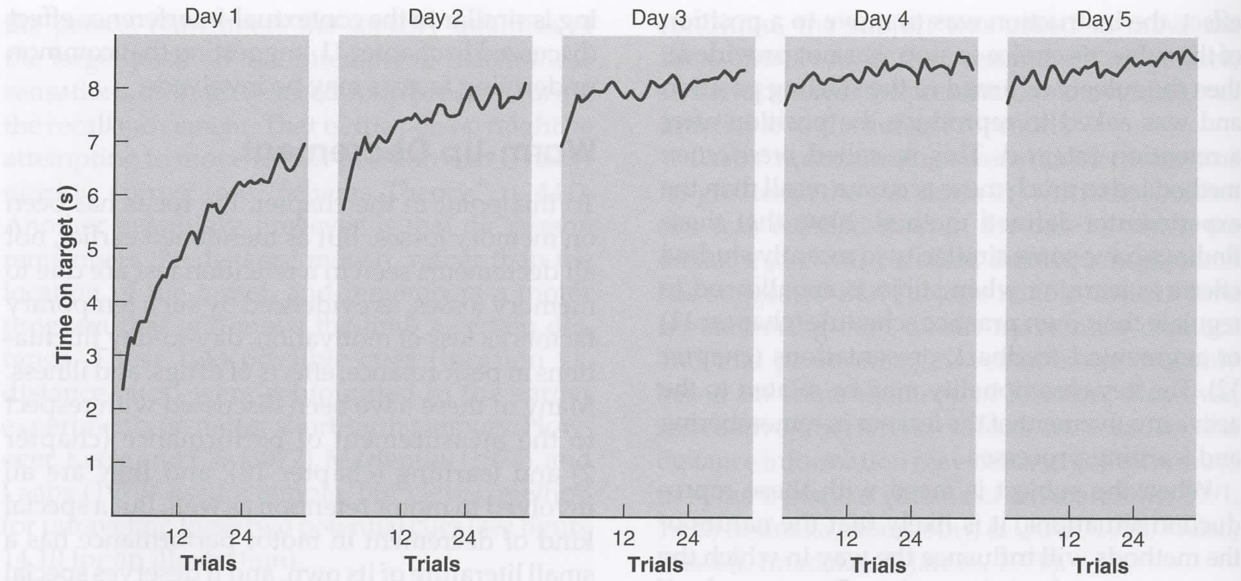

FIGURE 14.11 Mean performance on the pursuit rotor task for five days. (The decrements in performance from the end of one day until the beginning of the next are termed "warm-up decrement.")

Reprinted from J.A. Adams, 1961, "The second facet of forgetting: A review of warm-up decrement," *Psychological Bulletin* 58: 260.

or states. These views and the evidence for them are contrasted in the following sections.

Warm-Up Decrement as Forgetting

One major hypothesis, and probably the earliest and simplest explanation to be considered, is that warm-up decrement is simply another form of forgetting—that is, the loss of memory for the skill. In this view, the rest period allows certain forgetting processes to occur, with the initial phases of these processes being relatively rapid. These account for the rather large performance decrements seen with only a few minutes of rest. The improvements in performance with resumed practice are, in this view, due to relearning of the task whose memory was weakened over the rest period. This view does not seem to hold well for continuous skills, which as we have discussed, are retained well for long periods of time but also show substantial warm-up decrements. In general, there appears to be little support for a memory-loss explanation of warm-up decrement (Stratton, Liu, Hong, Mayer-Kress, & Newell, 2007).

Warm-Up Decrement as a Loss of Set

In another view, the loss of skill is related to the loss of *set*—one or more temporary internal states that underlie and support the skill in question. Set could consist of postural adjustments, orientation of attention to the feedback channel that is relevant for the task (e.g., vision vs. kinesthesis), adjustments in emotional state, and many more. According to this view, warm-up decrement is caused by the loss (or disruption) of these adjustments (set) over the rest period. The hypothesis says that *memory* of the skill is not lost over the rest period; or perhaps very small memory losses do occur, but they are far too small to account for the large decrements seen. With practice resumed on the task after the rest, performance is improved because the internal set (or adjustments) that supports the skill is reinstated.

Early Evidence on the Set Hypothesis The set hypothesis seemed reasonable for many years, as it is easy to imagine how such a process might disrupt skills with rest, especially in the face of the nearly perfect retention of skills like those in the pursuit rotor task. Yet no evidence existed for these set-loss phenomena until Irion's (1948) data with verbal skills suggested a way to study the problem. Irion's idea was that it should be possible to reinstate a lost set through certain activities that are related to the action in question but that cannot be thought of as contributing specifically to the memory for it. Irion used verbal learning as the main task, with two groups; both practiced the verbal task, then had a rest, then resumed practice again. One of the groups remained inactive during the rest period. The other group engaged in color naming during the end of the rest period—an activity presented on the same apparatus and having the same rhythms as the verbal-learning task but using none of the learned items from the main task. If the set hypothesis is correct, color naming should reinstate the lost set produced by the rest, and the initial performance on the verbal-learning task should be more accurate than for the group that simply rested. It was. Because color naming cannot be argued to increase memory strength for the verbal task, the implication is that color naming reinstated the lost set, in some way *preparing* the subjects for the upcoming verbal task.

Numerous studies were done to evaluate the set hypothesis with motor skills, but with few successes. In one such investigation, Ammons (1951) used the pursuit rotor; during the rest he had subjects watch another active subject or follow the target area with the finger, for example, in an attempt to eliminate warm-up decrement. No procedures were found that would eliminate it (see Adams, 1955). These data seemed to say that either (a) the set hypothesis was wrong for motor behavior or (b) the appropriate non-memory-set–reinstating activities had not been studied. In either case, the set hypothesis was not well supported. This evidence is reviewed more completely by Adams (1961, 1964) and by Nacson and Schmidt (1971).

Recent Evidence on the Set Hypothesis Nacson and Schmidt (1971) tested the set hypothesis and provided considerable support for it. Their idea was that during practice, various supportive mechanisms are adjusted constantly so that performance is maximized; then, during rest, these functions are adjusted to levels most compatible with resting, leading to an ineffective pattern of adjustment when the task is resumed. Practicing a task requiring the same adjustments (set) as the main task just before returning to it should reinstate those adjustments, leading to a reduction in warm-up decrement, just as Irion (1948) had found with color naming.

The task used by Nacson and Schmidt (1971) involved a right-hand force production; the subject had to learn to squeeze a handle with a 21 kg force, with KR given after each trial and 10 s rest between trials. After trial 20, a 10 min rest was given, and then practice resumed for another 10 trials. The independent variable was the nature of the activities presented in the 10 min rest period. One group (Rest) was allowed to rest for 10 min. Another group (Exp) had 5 min of rest, followed by 5 min of another force-estimation task; this task, though, involved the left arm rather than the right arm, elbow flexors rather than the gripping action, and a different level of force (9 kg). So it could not be argued that this task would contribute to the memory of the right-hand grip task. After 18 trials of this task with the same intertrial interval and KR, subjects were shifted immediately to the right-hand grip task for the retention test.

The absolute errors in the main (right-hand gripping) task are shown in figure 14.12 for the two groups before and after the rest period. The group that simply rested (Rest) for 10 min showed the typical warm-up decrement after the rest; but the group with the left-hand activities (Exp) showed very little warm-up decrement, suggesting that the activities in the rest period reinstated the lost set. Similar findings have been shown for a linear-positioning task (with a positioning task as the warm-up task) by Nacson and Schmidt (1971; Schmidt & Nacson, 1971), and by Schmidt and Wrisberg (1971) using a movement-speed task (with another movement-speed task as the warm-up task). These data also argue against the hypothesis that warm-up decrement is simply forgetting; a forgetting hypothesis cannot explain why a different warm-up task (which seems to have no memory elements in common with the main task) should produce improvements in main-task performance.

Other data (Schmidt & Nacson, 1971) showed that the reinstated set was rather transient in nature. If as few as 25 s of rest were inserted between the reinstatement of the set and the resumption of practice on the main task, the set was completely lost again. Also, activities can be designed that will *increase* warm-up decrement even more than resting does. For example, Schmidt and Nacson (1971) showed that a grip strength task (with maximum force) performed just before the resumption of practice on a linear-positioning task caused a very large increase in error on the first postrest trial, suggesting that the maximum-grip task required a set that was incompatible with the set for linear positioning. Other experiments indicate that *imagery* practice of the task just prior to the resumption of performance can reduce the warm-up decrement,

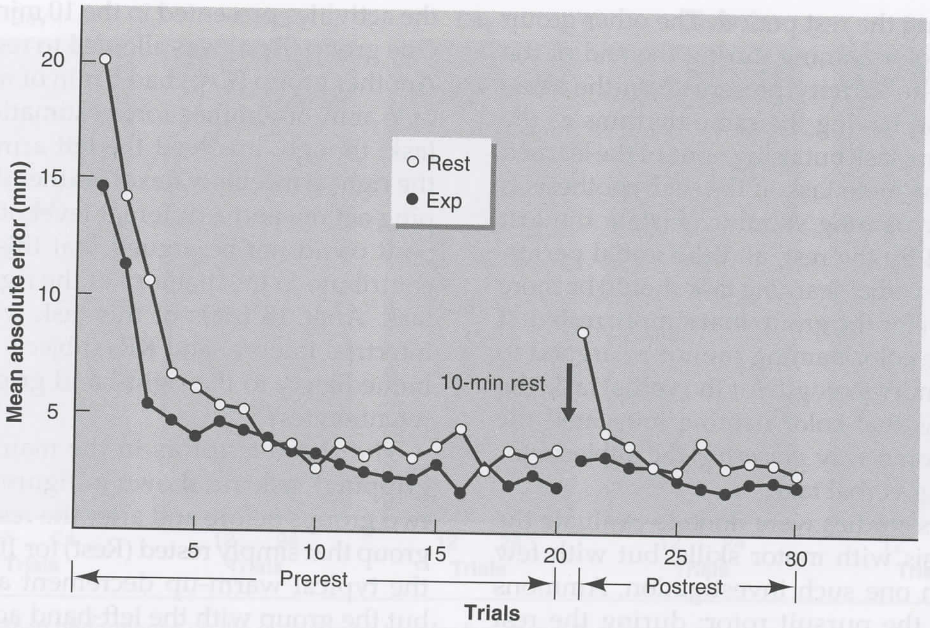

FIGURE 14.12 Absolute error in a force-estimation task for original learning and after a 10 min rest. Group Rest rested during the interval, and group Exp performed a left-hand force-estimation task; error is measured as a polygraph pen displacement.

Adapted, by permission, from J. Nacson and R.A. Schmidt, 1971, "The activity-set hypothesis for warm-up decrement," *Journal of Motor Behavior* 3: 1-15, adapted with permission of the publisher (Taylor & Francis Ltd, http://www.informaworld.com).

although the nature of the reduction seems to be task specific (Ainscoe & Hardy, 1987; Anshel & Wrisberg, 1988, 1993; Wrisberg & Anshel, 1993).

In sum, these findings suggest that warm-up decrement is caused by some loss of internal adjustments (or set) over the rest period. These adjustments are critical to effective performance in the task, but they are not a part of the memory for it. Just as a race car needs to attain the proper temperature before maximal performance can be achieved, so too, it appears, must the human be brought into the proper state of (temporary) adjustment for high-level skilled performance. It is not clear exactly what is being adjusted in these experiments, but probable candidates are the level of arousal, the rhythm and timing for the trial cycle, attention to the proper focus and sources of feedback, and so on.

These findings have considerable relevance for high-level performances, especially after performance is interrupted by rest or when major changes in tasks are required. For example, in golf, there are probably different sets for driving and putting, each of which must be reestablished before each shot. Watch professional golfers before they execute a swing; or watch professional basketball players before they take a free throw. Most players carry out a "preshot routine"—a sequence of actions and thoughts that are specific to each athlete, but done consistently by that athlete from shot to shot. It is tempting to suggest that the preshot routine is a method that reinstates the set and helps to overcome warm-up decrement (Boutcher & Crews, 1987), and some evidence exists to support the contention (Mack, 2001). However, much more research could be done to more fully investigate the idea.

Consolidation

An old concept in motor learning research, which dates back well over a century (see McGaugh, 2000, for a historical review), has received renewed interest in recent years. Much of the current work is being conducted at the cellular level of analysis with animals, and is beyond the scope of discussion here. However, a significant amount of research has also been conducted at the behavioral level, with intriguing results.

The basic idea is that practice produces a memory for motor skill that is unstable for a period of time but that stabilizes, or "consolidates," during a critical period afterward. A frequently used method to examine consolidation uses a variant of the retroactive-interference paradigm discussed earlier. In this paradigm, one group learns task A, then immediately practices a second task (B). Another group undergoes the same learning procedures, except that a time interval is inserted prior to learning task B, which presumably allows for the consolidation of task A. Retention of task A is measured later for both groups.

This paradigm was used, for example, by Walker, Brakefield, Hobson, and Stickgold (2003) to examine the retention characteristics of a finger-sequencing task. Subjects who learned a different sequence (task B) immediately after practicing an initial sequence (task A) performed much less skillfully 24 h later in the retention trials of task A than subjects who delayed practice of task B by 6 h after initial practice of task A. This suggested that the 6 h rest allowed some consolidation of task A, rendering it less vulnerable to interference from task B. Moreover, these consolidation effects appear to be larger if the consolidation interval includes a period of sleep (Stickgold & Walker, 2006).

These findings are not without some controversy, however, as failures to find consolidation effects appear to be related to task-specific differences and experimental design issues (e.g., Criscimagna-Hemminger & Shadmehr, 2008; Krakauer & Shadmehr, 2006). These consolidation effects are also difficult to reconcile with variability-of-practice effects discussed in chapter 11, in which retention and transfer following practice on a single task are *less effective* than with practice on multiple tasks (e.g., Shea & Kohl, 1991). Nevertheless, the renewed interest in these retention issues has escalated motor learning research in a number of experimental laboratories, representing a current "hot topic" in the literature.

Transfer of Learning

A number of decisions about the design of practice sessions are based heavily on an understanding of transfer of learning—the gain (or loss) in proficiency in one skill as a result of practice on some other skill. Often, the task actually practiced in a session is not the activity of primary interest, the real concern being for some other task believed to be related to this activity. One example is the use of drills, in basketball for example. The instructor usually does not really care whether the student can perform these drills, per se, well; rather, the instructor assumes that, by practicing them, the student will learn something that will transfer to some other task that is of primary interest (e.g., performance in a basketball game). For drills to be successful, one must be certain that what is learned in practice on the drill transfers to performance of the desired *criterion task.*

Another example is the common method whereby the task is broken down into its components for practice. The assumption is that practice on the parts will transfer to the whole task (see chapter 11). Still another example is the use of simulators of various kinds, such as a pitching machine to simulate a "real" pitcher in baseball, a dummy for training resuscitation skills, or a simulator to duplicate an aircraft cockpit. Does practice on these simulators result in improved performance on the criterion task—that is, do learning skills using the simulator *transfer*? The choices about whether or not to use these methods, and about how they should be structured, if used, depend heavily on an understanding of transfer of learning. We consider some of the principles of motor transfer next.

Basic Principles of Transfer

Many studies using different techniques and tasks have produced a vast array of different and sometimes contradictory findings on transfer (see Cormier & Hagman, 1987, for a review). Two major points emerge from the work on motor skills. First, the amount of transfer seems to be quite small and positive unless the tasks are practically identical. Second, the amount of transfer depends on the "similarity" between the two tasks (Schmidt & Young, 1987).

Motor Transfer Is Small

When the transfer from one task to a completely different task—sometimes called *intertask transfer*—is studied, we typically find that the transfer is small or negligible. Such evidence comes from studies concerned with attempts to train some behavior or trait in one situation by providing presumably related experiences in different situations. For example, investigations by Lindeburg (1949) and Blankenship (1952) showed that "quickening exercises" (various laboratory tasks that require rapid decision and action) provided no transfer to other tasks that required quickness. This is certainly not surprising in light of what is known about the specificity of motor abilities (see chapter 9), as the activities in the quickening exercises probably used different motor abilities than the task to which the exercises were supposed to have contributed (see "The Myth of General Vision Training" on p. 486). Evidence suggests that general traits such as quickness, balance, and coordination cannot be improved by the use of different activities supposedly involving that trait; and we would not expect that an *ability* would be improved by practice anyway.

What if the tasks are more similar? Here, the transfer among tasks tends to be higher than for the previous situation, but still the amount of transfer is typically small. For example, figure 14.13 presents results from Lordahl and Archer (1958). Different groups of subjects practiced the pursuit rotor task on one day at 40, 60, or 80 rpm for 30 trials. All groups then switched to the 60 rpm version of the task for evaluation of the transfer effects on the next day. The group that had 60 rpm in both the training trials and the transfer trials was used as the standard against which the transfer in the other two groups was assessed (i.e., it served the role of group II in figure 14.2). Using the calculation for the percentage transfer introduced earlier in this chapter, the transfer from the 40 and 80 rpm versions of the task to the 60 rpm version was 12% and 31%, respectively, on the very first trial. And, as can be seen in figure 14.13, both groups required considerable practice on day 2 to achieve the same level of performance as attained by the 60–60 group at the end of day 1 practice. Namikas and Archer (1960), using the same procedures, found somewhat higher transfer, ranging from 42% to 64%. Remember that in these experiments the transfer is between the pursuit rotor and *itself*, with only the speed of rotation changed to define the different "tasks." It is somewhat surprising that the transfer is so small, but numerous other experiments show essentially the same thing.

These generally small transfer effects seem to fit with a number of other phenomena that we have discussed already. First, the transfer findings coincide with the ideas about individual differences. An important concept in chapter 9 was that motor abilities are both numerous and specific, and that even similar tasks appear to correlate very weakly with each other (with the possible exception of timing skills). If so, then in transfer experiments when the task is changed in even a small way (e.g., changing the turntable speed of the pursuit rotor), it is likely that different and unrelated abilities are called into play. Thus, there might be low transfer among even very similar tasks because the abilities involved are almost completely different.

These findings also fit well with the GMP notion. In chapter 6, a major idea was that two tasks with different relative timing characteristics were assumed to be governed by different GMPs.

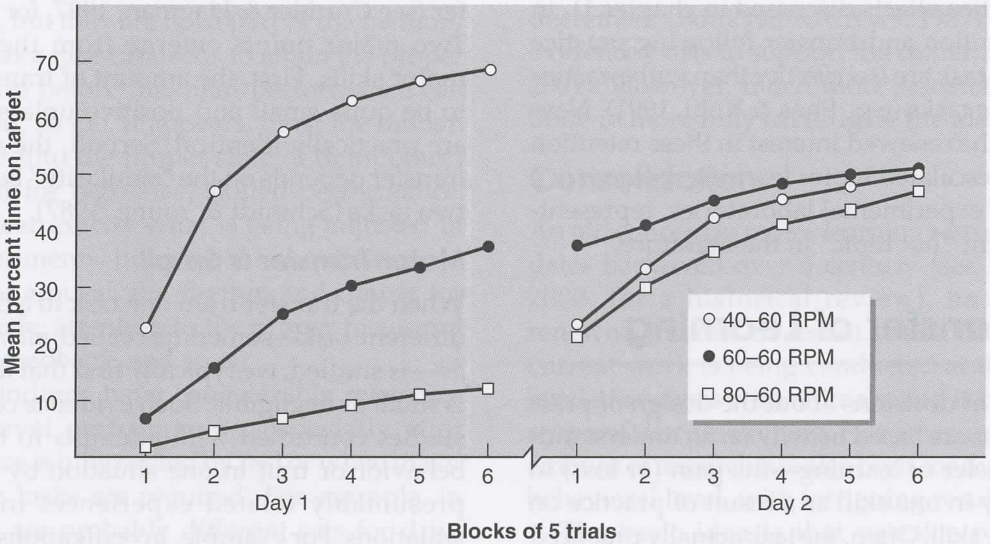

FIGURE 14.13 Mean time on target in pursuit tracking. Separate groups practiced on day 1 at speeds of 40, 60, or 80 rpm and transferred to 60 rpm on day 2.

Data from Lordahl and Archer 1958.

If a shift in conditions requires subjects to abandon one GMP in favor of another, then they will be performing two different GMPs in the two different variations of the "same" motor task. This is analogous to speeding up a treadmill so that jogging is substituted for walking, each activity having its own program (e.g., Shapiro, Zernicke, Gregor, & Diestel, 1981). It is difficult to say how wide the range of conditions produced by a given GMP might be, but we suspect that many GMPs exist and that they are shifted rather freely when the conditions change. Viewed in this way, it is not surprising that the tasks do not transfer to each other very strongly.

Transfer Depends on Similarity

A second and related concept is that transfer depends on the similarity of the two tasks being considered. The idea of similarity is certainly not new, as Thorndike (1906) and Woodworth (1901) proposed that transfer depends on the number of "identical elements" that exist in common between two tasks. If one task had elements that were totally different from the elements in another task, then no transfer would be expected. Transfer would be 100% if the two tasks had all their elements in common. The problem with this theory was that it never specified what an "element" was and how it could be operationalized, so the theory cannot be put to empirical test. In the previous paragraphs, the implication is that the "elements" could be (a) abilities in common between the two tasks, (b) GMPs that are used for the two tasks, or (c) both. And other possibilities exist.

The theories of transfer have been improved considerably since the publication of this next idea. A major contribution was Osgood's (1949) *transfer surface,* which provided a description of the amount of transfer of *verbal* learning as a joint function of the similarity of the stimulus elements and the response elements. Holding (1976) presented a related idea for motor skills. In all these cases, the notion of similarity is a dominant theme, as it always has been. But these recent theories are not completely satisfactory, as a large number of transfer phenomena do not appear to be explained by them. The problem seems to be related to our lack of understanding about what "similarity" is and what the "elements" are that are supposedly transferred across various tasks. Perhaps research with abilities and motor programs will contribute to this area, but to date this possibility has not been realized. The conclusion from a look at this literature is that motor transfer is still not well understood at all (Schmidt & Young, 1987).

Negative Transfer

We have mentioned that transfer is not always positive and that losses can occur in one skill as a result of experience on another. This is called *negative transfer.* Many people believe that negative transfer is relatively common and that the skill losses it produces can be quite large. Almost cliché is the story that tennis in the summer ruined the person's badminton game in the winter, presumably because the two tasks are quite similar yet somewhat incompatible (e.g., the wrist action in the two strokes is different). But the research on transfer nearly always shows low but positive transfer; negative transfer is seldom the outcome. However, negative transfer can be produced if the proper conditions are presented, such as those provided by Lewis, McAllister, and Adams (1951). Lewis and colleagues used the Mashburn task, in which a two-dimensional arm control and a foot control are operated simultaneously to match the positions of lights on a display. After subjects practiced for a varying number of trials (either 10, 30, or 50) with the usual configuration of the task, they were switched to a condition in which the control–display relationships were reversed. For example, in order to move the light on the display to the left, the lever had to be moved to the right rather than to the left as had been the case before. All three dimensions of the task (right-left, backward-forward, right foot–left foot) were reversed. This is analogous to driving a car in which the "normal" movements of the controls are suddenly backward (e.g., steering wheel turned clockwise to go left, brake pedal released to stop). After 10, 20, 30, or 50 trials on this reversed task, subjects were switched back to the original configuration of the task to examine whether skill on it had been lost or gained. This is a retroactive-transfer design (as shown in table 14.3).

The differences on the main task between the number of matches before and after reversed-task practice are plotted in figure 14.14 (see p. 485). A decrement score of zero means that the standard task was performed just as well after the reversed task as before, meaning that no negative (or positive) retroactive transfer occurred; larger decrement scores imply more negative transfer. Transfer was generally negative, and negative transfer increased as the number of reversed-task trials increased. This is what one might expect,

The Myth of General Vision Training

A quick search of the Internet will reveal a growing industry that markets various "training programs" designed to improve vision. Some of these programs make the further claim that improvements in vision will transfer to improvements in performance, most notably sport performance. These claims are rather impressive, if not surprising, given that the amount of motor transfer between two tasks is normally small and restricted to training tasks that are highly similar to the transfer task (e.g., Lordahl & Archer, 1958; Schmidt & Young, 1987). However, a close look at the "evidence" provided in support of these programs quickly reveals it to be weak, biased, and perhaps even fraudulent.

Sport vision training programs generally make the following claims: (1) Superior athletes have superior visual skills; (2) visual skills can be improved with training; and (3) visual skills that are trained in sport vision programs will result in superior sport performance (Abernethy & Wood, 2001; Starkes, Helsen, & Jack, 2001; Williams & Grant, 1999). The first claim, that superior athletes have superior *visual* skills, has little to no support. Instead, the evidence suggests that superior athletes often have a *perceptual advantage*—that is, experts process specific sport-related perceptual information faster and more precisely than less skilled athletes (Starkes et al., 2001; Williams & Ward, 2003). Experts are similar to less skilled athletes in speed and precision in processing perceptual information (and visual information in general) that is not specific to the nature of their expertise (Starkes & Ericsson, 2003).

The second claim, that general visual skills can be trained, is misleading. There does appear to be evidence that some improvement can be gained from general visual skills training, but this benefit is limited to individuals with visual defects. In their review of the literature, Abernethy and Wood (2001) conclude that there is no evidence that visual skills can be improved in *athletes* as appears to be the case for individuals with compromised vision.

The last claim, that general visual skills training programs can improve sport performance, appears highly suspect or fraudulent. The "strongest" support is provided by case testimonials, usually by athletes who have undergone the training program. However, testimonials are not experimental evidence, and any *perceived* benefit could be due to expected improvements (i.e., a Hawthorne effect). As we have suggested many times in this book, *transfer* is a highly selective and specific process. There is no evidence at all, for example, that intensive "training" to respond to a stimulus light in the midst of a complicated array will facilitate auto racing performance. Tracking a swinging ball with ocular and finger pursuit movements will not improve forearm shots in tennis. And, trying to identify an alphanumeric character presented in a tachistoscopic display will never help a batter to distinguish between a fastball and a curveball. The conclusion regarding this third claim—that general vision training can improve sport performance—appears to be an overwhelming "no!" based on theory and empirical evidence (Abernethy & Wood, 2001).

as the amount of interference from this reversed task should be larger if it is learned more completely. (There was also an effect of the number of original-practice trials of the task with standard controls, but it is far from clear what this means; see Schmidt, 1971a, for a more complete discussion of this effect.) This is an example of clear and unmistakable negative retroactive transfer; similar findings have been produced in other studies using similar procedures (see Lewis, 1953; Schmidt, 1971a; Schmidt & Young, 1987).

However, the negative transfer produced in these studies seemed mainly cognitive and may not have had much to do with *motor* negative transfer. The reversed conditions probably left the subjects confused about what to do (which way to move) and may not have disrupted the motor control processes in the task at all. This argument is not strong, though, as it is difficult to know what the relevant motor and cognitive processes are in such tasks. Yet it seems logical to assume that a major portion of the problem for the subjects on returning to the standard task was confusion about what the limbs controlling each of the three dimensions of the task were supposed to do.

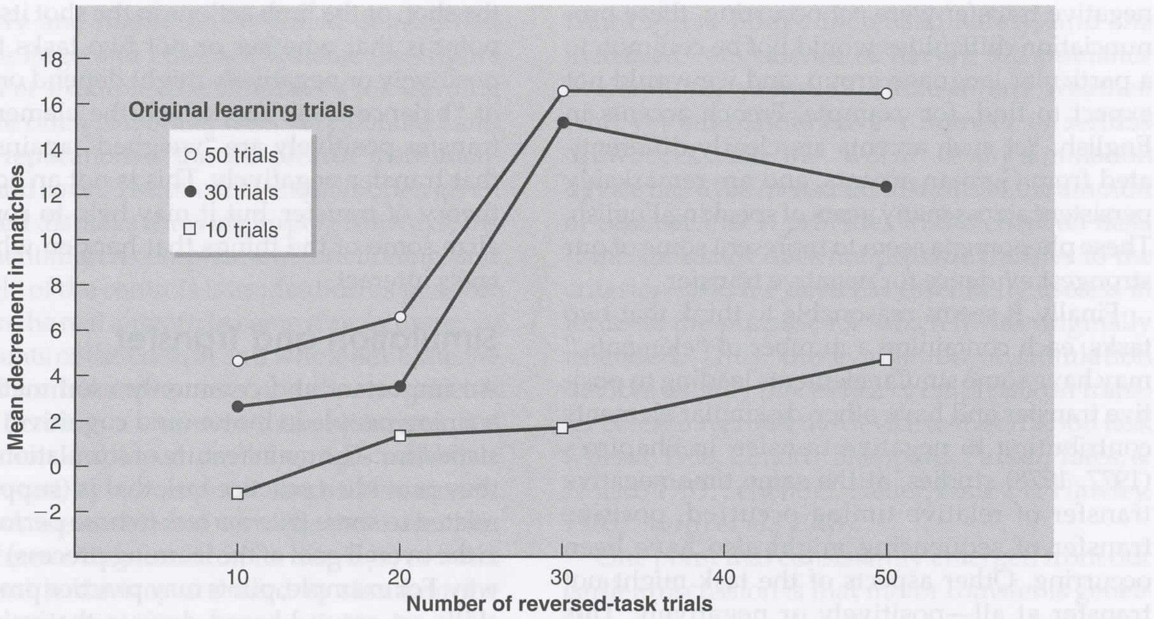

FIGURE 14.14 Retroactive negative transfer (interference) as a function of amount of practice on the reversed task and the amount of original practice on the standard task.

Reprinted from D. Lewis, D.E. McAllister, and J.A. Adams, 1951, "Facilitation of interference in performance on the modified mashburn apparatus: I. The effects of varying the amount of original learning," *Journal of Experimental Psychology* 41: 53.

Negative Transfer of Timing

Some studies suggest, however, that negative transfer of limb control can be quite large. For example, Shapiro (1977, 1978) had subjects learn complex patterns of movements with a particular relative timing. Later, subjects were instructed to speed up the movement, maintaining the same relative timing, which they had no trouble doing. But when they were told to *ignore* the temporal pattern they had learned earlier, subjects had a great deal of difficulty producing a new temporal structure. Instead, they sped up the original temporal structure, more or less as one would speed up a phonograph record. (These studies are discussed in more detail in chapter 6.) This can be seen as a kind of negative transfer, where the prior experience with the "old" temporal structure interfered with producing the "new" pattern at maximal speed. This might turn out to be an important finding for understanding transfer. Schmidt and Young (1987) suggest that tasks whose relative timing and sequencing are the same will tend to transfer to each other positively; two tasks whose sequencing is the same, but whose timing is different, will tend to transfer to each other negatively; most tasks with neither sequencing nor timing in common transfer to each other hardly at all.

Similar effects for learning new coordination-timing patterns were described in chapter 13. Strong negative-transfer effects are exerted by the existing, stable patterns (in-phase and anti-phase patterns) when one attempts to learn a new pattern, such as a 90° relative-phase coordination (Zanone & Kelso, 1992; Lee, Swinnen, & Verschueren, 1995). This suggests that some negative transfer can result from the experiences that subjects bring into the laboratory (i.e., before learning any specific task). Certainly much more can be discovered about negative transfer effects from this kind of research.

Another example involves second-language learners; here we consider the production of a particular language's speech sounds (but not its grammar or vocabulary) as a motor skill. Common experience tells us that the difficulty in producing a particular speech sound in English, for example, is critically related to the speaker's first language. The same acoustic goal is often produced differently by speakers whose native language is French versus German; these difficulties represent negative transfer from French (or German) to English. (One of us, R.A.S., was never able to perform the common "ui" sound in Dutch [e.g., "bruin"], despite much practice.) If negative transfer were *not* occurring, these pronunciation difficulties would not be common to a particular language group, and we would not expect to find, for example, French accents in English. Yet such accents are clearly differentiated from German accents, and are remarkably persistent across many years of speaking English. These phenomena seem to represent some of our strongest evidence for negative transfer.

Finally, it seems reasonable to think that two tasks, each containing a number of "elements," may have some similar elements leading to positive transfer and have other, dissimilar elements contributing to negative transfer. In Shapiro's (1977, 1978) studies, at the same time negative transfer of relative timing occurred, positive transfer of sequencing might also have been occurring. Other aspects of the task might not transfer at all—positively or negatively. This idea can be seen in many tasks in sports, for example handball and racquetball. There appear to be many common elements between these two games, such as the angles that the ball bounces off the walls of the court and the strategies of the game, all of which might lead to positive transfer (e.g., Smeeton, Ward, & Williams, 2004). Yet at the same time, other elements of the game would appear to lead to negative transfer, such as the exact positioning of the body just before the shot, or the limb actions in the shot itself. The point is that whether or not two tasks transfer positively or negatively might depend on a kind of "balance sheet" on which the elements that transfer positively are "weighed" against those that transfer negatively. This is not an adequate theory of transfer, but it may help to conceptualize some of the things that happen when two tasks interact.

Simulation and Transfer

An important and commonly used method for training people in motor (and cognitive) tasks is *simulation.* The main feature of simulations is that they provide a practice task that is (supposedly) related to some *criterion task* (whose performance is the overall goal of the learning process) in some way. For example, pilots may practice procedural skills on ground-based devices that mimic the cockpit of the airplane, as seen in figure 14.15. The reasoning is that the practice of these skills in the simulator will transfer to the actual skills in the airplane (the criterion task). Many aspects of simulators were reviewed in Sweezy and Andrews (2001).

Physical Simulators

Many examples of simulators in learning situations could be mentioned. At one end of the scale are

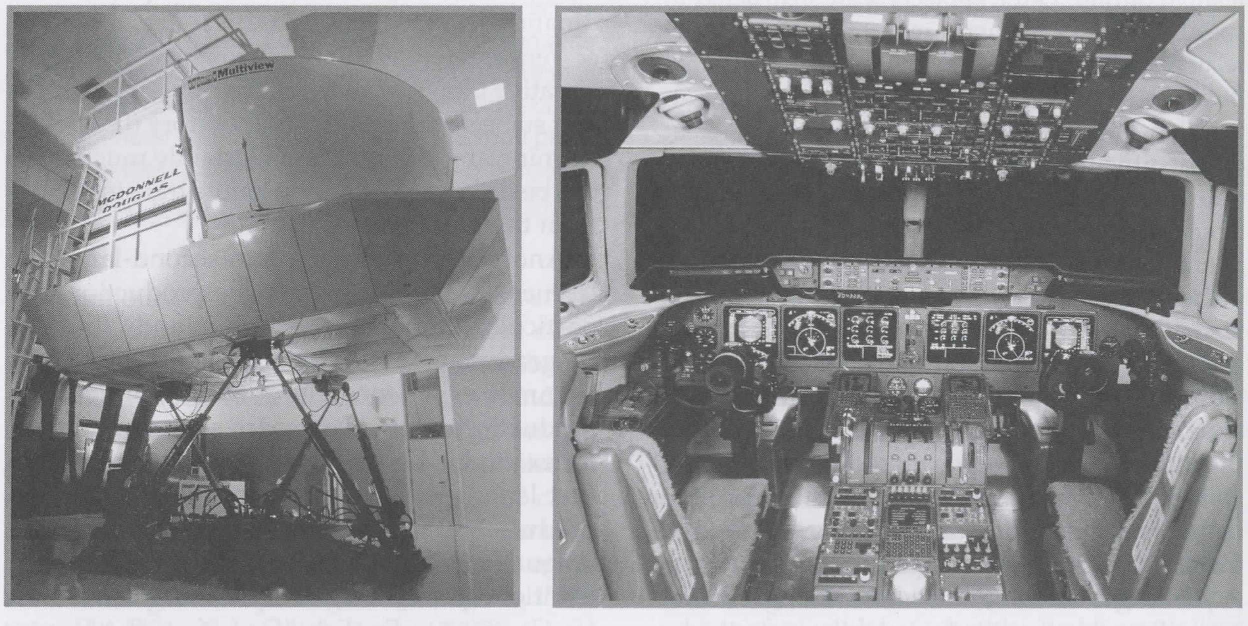

FIGURE 14.15 The MD-11 flight simulator.

Copyright © Boeing.

expensive and highly sophisticated devices that simulate large and complex systems (see figure 14.15). For example, the simulators for learning to fly are often elaborate, with very detailed and specific replications of the cockpit area, instrumentation, and so on. The pilot or learner is often given simulated displays showing airport runways; the instrumentation is complete and functioning; and the "feel" of the controls is as identical as possible to that in the real aircraft. In some simulators, even movements of the cockpit as a whole simulate the effect of control movements and the movements of the aircraft in a storm. In these situations, the information displayed on the gauges and dials is produced by a computer, and the learner's responses are monitored as well; these are then used to move the simulator, its displays, or both. Comparable devices are used to simulate the behavior of a weapons system, and simulators for controlling the behavior of nuclear power plants have been developed. As you might imagine, these devices are very expensive to produce, operate, and update.

Some of the early medical simulators were less expensive and could be used to train procedural skills, such as resuscitation. Low-fidelity mannequins such as Resusci-Annie were the precursor to higher-fidelity simulators that remain in use today for resuscitation and many other types of medical diagnosis and treatment training (Cooper & Taqueti, 2009; Perkins, 2007). The use of minimally invasive surgical procedures (e.g., laparoscopic surgery) seems to require simulators for training; these kinds of simulators are by now quite common and generally supported in the medical community (Sturm et al., 2008).

At the other end of the scale, simulation devices can be made that are relatively simple and inexpensive. Many of us learned to drive a car by practicing on driver simulators that had not-so-realistic configurations of an automobile's controls, so that we could learn the proper motions before we tried them in a real car. Some dental schools still use plaster-of-Paris models of the jaw—dentists-in-training practice dental skills with the "jaw" on a workbench or even in the position it would be in if it were the upper jaw of a patient. A simulator can require almost no apparatus; for example, you can practice golf putting on a living room rug with a glass lying on its side on the floor.

Physical simulators provide a number of advantages, such as decreased cost or time of training (or both), increased safety, and the increased convenience of having the simulator available for use at any time in any weather. And yet simulators have a number of serious drawbacks. First, the "worth" of any simulation device has to be measured in terms of the amount of transfer that it provides to the criterion task. If the simulator does not provide transfer to the criterion task, the device is essentially useless in terms of the purpose for which it was originally intended. Thus, the evaluation of simulation devices usually places heavy emphasis on transfer of learning from the device to the criterion task (Alessi, 1988; Lintern, Sheppard, Parker, Yates, & Nolan, 1989; Schendel, Heller, Finley, & Hawley, 1985; Sturm et al., 2008).

One point that consistently emerged from our earlier discussion is that motor transfer is generally quite small unless the training and criterion tasks are so similar as to be practically identical. From these basic research findings, as well as from the literature on the specificity of individual differences (chapter 9) and specificity of learning (chapter 11), it might be predicted that many simulators will not transfer well to the criterion tasks for which they were designed. Certainly a critical part of simulator evaluation is the conduct of a transfer experiment, perhaps with various versions of the simulator, to evaluate the amount of transfer that is actually produced. Transfer should increase from the simulator to the criterion task to the extent that the two are similar. Recognition of this fact has led the designers of simulation devices to make them very realistic—for example, the simulated airplane cockpit that moves as the actual aircraft would if it were in a storm. Much effort is devoted to making the controls feel as they do in the airplane, with proper resistances, feedback, and so on to maximize the similarity. This makes good sense. If differences between simulator and criterion task are too great, it is possible that separate motor control mechanisms might be learned in the two situations, producing no transfer to the criterion task.

Simulation devices are usually excellent for teaching *procedural skills,* the proper order of a sequence of activities, and the like. These aspects of the overall task are important, and considerable time can be "saved" by using simulators at early stages of practice, as sequence knowledge appears to be transferable between different effector systems (Fendrich, Healy, & Bourne, 1991;

Keele, Jennings, Jones, Caulton, & Cohen, 1995). There is less certainty that the motor elements of the task are so easily simulated, however.

Simulations are often applied rather blindly without regard for the kinds of transfer that will be produced. Many examples are seen in athletics, in which certain kinds of behaviors are simulated in various drill procedures. The use of blocking dummies in American football may be helpful in the early stages of learning a play when the athletes have questions about where to go and whom to block, but there would seem to be little utility in using them beyond this point. Players would seem to require practice in blocking other players who do not wish to be blocked; this is, of course, very difficult to simulate. It is difficult to evaluate the effectiveness of these various procedures because we have no research about the transfer of these drills to game situations. Our guess is that the faith placed in many of these procedures is probably overdone. Certainly it would make sense to examine any such drills or simulations very carefully.

Virtual Simulators

In contrast to the traditional type of physical simulators for use in training new skills are simulators that use computer-based technologies to train the perceptual–motor attributes of criterion tasks. *Virtual environments* often simulate the perceptual (visual, auditory, and haptic) demands of a task, together with a simulated effector system, and display these on a computer monitor. The actions of a subject can be mapped in terms of the actions of the simulated effector system, with the expected (computer generated) consequences displayed. One advantage of such devices is that they are much less costly to produce than many of the physical simulators already discussed. And, once developed, these computer programs should be modifiable so that newer versions need not be built again from scratch.

In recent years, one of the fields that has been developing virtual environments the fastest is the medical field. Arnold and Farrell (2002) critically reviewed the early evidence and concluded that virtual reality was, at the time, unverified as a positive training aid for surgical motor skills. The potential for positive motor skills transfer, however, has been elevated by the use of robotic devices that provide simulated haptic and proprioceptive feedback (see figure 2.16, p. 44). For example, robotic devices can provide the medical student with visual, auditory, and haptic feedback as a cut is made through bone or other tissue, thereby providing numerous sources of augmented information during training. Although researchers still await conclusive evidence about how to optimize virtual reality training (Fialkow & Goff, 2009; van der Meijden & Schijven, 2009), we suspect that the attempt to make training as task specific as possible can only be a positive advance for motor transfer. That said, we know from the literature on augmented feedback (chapter 12) that complex and sophisticated feedback in simulators can be detrimental for learning if it is not used appropriately.

In contrast to expensive, high-fidelity training simulators, some researchers and practitioners are now using commercially available hardware and software to explore skill transfer. For example, the Nintendo Wii is a hugely popular gaming system that combines many different types of part- and whole-body movements together with interactive visual and haptic feedback experiences. Physical therapists, for example, have employed the Wii to motivate active participation in movement-related activities, and have reported positive effects for an individual with cerebral palsy (Deutsch, Borbely, Filler, Huhn, & Guarrera-Bowlby, 2008). And in a rather surprising finding of transfer generality, extensive video gaming experience appears to be causally related to enhancements in visual attention (Dye, Green, & Bavelier, 2009; Green & Bavelier, 2003, 2006). The capability for using inexpensive yet sophisticated gaming systems in these studies represents an exciting new development for future skills transfer research.

Summary

Learning, memory, retention, and transfer are very closely related concepts. Motor memory is the persistence of the acquired capability for responding, and losses in memory are called forgetting. Forgetting is usually measured by performance losses on a retention test, administered after a retention interval. Different measures of retention can be computed, although the absolute-retention measure is the most useful.

A variant of the learning experiment is the transfer experiment, in which the effect of practicing one task on the performance of some other (criterion) task is evaluated. Transfer is often measured as a percentage, indicating the proportion of performance improvement in one task that was achieved by practice on the other task. Studies of transfer are important for evaluating training, simulation, and other instructional issues.

Continuous skills are retained nearly perfectly over long retention intervals. Discrete skills, on the other hand, can show marked performance losses during the same retention intervals. The reasons for this difference in retention are not clear, but they are probably not based on the tendency for continuous tasks to be more "motor" than discrete tasks. Perhaps the difference has its basis in the idea that continuous tasks, with more practice time in a typical experiment, are more resistant to forgetting because they are learned more completely.

The loss of information related to motor performance can occur in various possible ways. Information might decay from memory due to a passive process, or might be lost due to retroactive or proactive interference. Warm-up decrement is a retention loss caused by the imposition of a short rest in a series of practice trials. Research supports the set hypothesis to explain it, which holds that warm-up decrement is a loss, during rest, of a pattern of temporary nonmemory adjustments critical to performance. Consolidation of motor memories, a field of study that has recently reemerged, suggests that the interfering effects of learning a competing task are time dependent.

Two basic principles of transfer are (a) that motor transfer is usually small but positive and (b) that motor transfer depends on the similarity between tasks. Considerable difficulty exists in understanding the underlying basis of similarity, however. Negative transfer can be produced under certain conditions, but it is probably mostly cognitive in nature. Devices such as simulators and virtual environments provide promise for positive transfer, although their value seems to be highly specific to the similarity between the training and transfer tasks.

Student Assignments

1. Prepare to answer the following questions during class discussion:
   a. Using practical examples of discrete and continuous skills, illustrate the differences in expected retention characteristics.
   b. Describe three workplace examples in which warm-up decrement might be expected to occur after a lunch break.
   c. Suggest a computer simulation game that could be used to train physicians who are learning a microsurgery technique. Describe three key features of the simulation that should be particularly effective for learning.
2. Find a research article that was designed to examine the short-term retention characteristics of movement information.

Web Resources

This Web site provides a history of virtual reality:

http://archive.ncsa.illinois.edu/Cyberia/VETopLevels/VR.History.html

More on virtual reality applications:

http://human-factors.arc.nasa.gov/web/hf101/reference.html

Notes

[1] Robert Bjork tells us that Stanford University's first president, David Starr Jordan, who was an ichthyologist (i.e., he studied fish), once said that every time he learned the name of a new student he forgot the name of a fish—a clear example of retroactive interference.