CHAPTER

The Stages of Learning

Concept: Distinct performance and performer characteristics change during skill learning

APPLICATION

Have you ever noticed that people who are skilled at performing an activity often have difficulty teaching that activity to a beginner? This difficulty is due in part to the expert's failure to understand how the beginner approaches performing the skill each time he or she tries it. To facilitate successful skill acquisition, the teacher, coach, or therapist must consider the point of view of the student or patient and ensure that instructions, feedback, and practice conditions are in harmony with the person's needs.

Think for a moment about a skill you are proficient in. Remember how you approached performing that skill when you first tried it as a beginner. For example, suppose you were learning the tennis serve. Undoubtedly you thought about a lot of things, such as how you held the racquet, how high you were tossing the ball, whether you were transferring your weight properly at contact, and so on. During each attempt and between attempts, your thoughts focused on fundamental elements of the serve. Now, recall what you thought about after you had had lots of practice and had become reasonably proficient at serving. You probably did not continue to think about all the specific elements each time you served. If you continued practicing for many years so that you became skilled, your thoughts while serving undoubtedly changed even further. Rather than thinking about the specific elements involved in serving, you could concentrate on other aspects of the skill. Although you still concentrated on looking at the ball while tossing it and during contact, you also thought about things like where you were going to place this serve in your opponent's service court, or what you were going to do after you served.

Although this performance example involves a sport skill, the underlying concept helps explain the difficulty experienced by skilled people teaching beginners in all skill instruction contexts. In the rehabilitation clinic, for example, the same problem exists. Imagine that you are a physical therapist working with a stroke patient and helping him or her regain locomotion function. Like the tennis pro, you are a skilled performer (here, of locomotion skills); the patient is like a beginner. Although there may be some differences between the sport and the rehab situations because the patient was skilled prior to the stroke, in both cases you must approach skill acquisition from the perspective of the beginner.

In the examples just described, we have seen that different characteristics distinguish beginners from skilled people. At the instruction level, this indicates that the skilled person teaching the beginner must approach performing the skill the way he or she did as a beginner. The extent to which the skilled person can do this will influence the degree of success he or she has teaching beginners. In addition, those who teach or coach skilled people likewise must understand characteristic of the skilled performer. In both cases, those who provide motor skill instruction benefit from being aware of those characteristics people demonstrate at these different skill levels.

DISCUSSION

An important characteristic of learning motor skills is that all people seem to go through distinct stages as they acquire skills. Several models have been proposed to identify and describe these stages. We discuss two of the more influential of these next.

The Fitts and Posner Three-Stage Model

Paul Fitts and Michael Posner presented the acknowledged classic learning stages model in 1967. Their model continues to be referred to by researchers today. They proposed that learning a motor skill involves three stages. During the *first stage,* called the **cognitive stage** of learning, the beginner focuses on cognitively oriented problems. For example, beginners typically try to answer questions such as these: What is my objective? How far should I move this arm? What is the best way to hold this implement? Where should this arm be when my right leg is here? Additionally, the learner must engage in cognitive activity as he or she listens to instructions and receives feedback from the instructor.

Performance during this first stage is marked by a large number of errors, and the errors tend to be large ones. Performance during this stage also is highly variable, showing a lack of consistency from one attempt to the next. And although beginners may be aware that they are doing something wrong, they generally do not know what they need to do to improve.

The *second stage* of learning in the Fitts and Posner model is called the **associative stage** of learning. The cognitive activity that characterized the cognitive stage changes at this stage, because the person has learned to associate certain environmental cues with the movements required to achieve the goal of the skill. The person makes fewer and less gross errors since he or she has acquired the basic fundamentals or mechanics of the skill, although they need to be improved. Because this type of improvement still is required, Fitts and Posner referred to this stage as a *refining* stage, in which the person focuses on performing the skill successfully and being more consistent from one attempt to the next. During this refining process, performance variability begins to decrease. Also during this associative stage, people acquire the capability to detect and identify some of their own performance errors.

After much practice and experience, which can take many years, some people move into the **autonomous stage** of learning, which is the *final stage* of learning. Here the skill has become almost *automatic,* or habitual. People in this stage do not consciously think about what they are doing while performing the skill, because they can perform it without conscious thought. They often can do another task at the same time; for example, they can carry on a conversation while typing. Performance variability during this stage is very small: skilled people perform the skill consistently well from one attempt to the next. Additionally, these skilled performers can detect their own errors, and make the proper adjustments to correct them. Fitts and Posner pointed out the likelihood that not every person learning a skill will reach this autonomous stage. The quality of instruction and practice as well as the amount of practice are important factors determining achievement of this final stage.

It is important to think of the three stages of the Fitts and Posner model as parts of a continuum of practice time, as figure 12.1 depicts. Learners do not make abrupt shifts from one stage to the next. There is a gradual transition or change of the learner's characteristics from stage to stage. Because of this, it is often difficult to detect which stage an individual is in at a particular moment. However, as we will consider in more detail later in

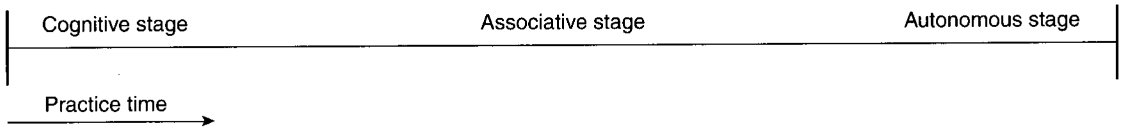

FIGURE 12.1 The stages of learning from the Fitts and Posner model placed on a time continuum.

this discussion, the beginner and the skilled performer have distinct characteristics that we can observe and need to understand.

Gentile's Two-Stage Model

Another model that motor learning researchers commonly refer to was proposed by Gentile (1972, 1987, 2000). In contrast to Fitts and Posner, she viewed motor skill learning as progressing through two stages, and presented these stages from the perspective of the goal of the learner in each stage.

In the *first stage* the goal of the learner is **"getting the idea of the movement."** We can understand the "idea of the movement" in general terms as what the person must do to achieve the goal of the skill. In movement terms, the "idea" involves the *appropriate movement coordination pattern* required for achieving the action goal of the skill. For example, if a person is rehabilitating his or her capability to reach for and grasp a cup, the person's focus in the first stage of learning is on acquiring the appropriate arm and hand coordination that will lead to his or her successfully reaching for and grasping a cup.

In addition to establishing the basic movement pattern, the person also must learn to *discriminate between environmental features* that specify how the movements must be produced from those that do not influence movement production. Gentile referred to these features as regulatory and nonregulatory environmental conditions. You may recall from the discussion in chapter 1 of Gentile's taxonomy of motor skills that *regulatory conditions* are characteristics of the performance environment that influence, i.e., regulate, the characteristics of the movements used to perform the skill. In the example of learning to reach for and grasp a cup, the regulatory conditions include information such as the size of the cup, the shape of the cup, the distance the cup is from the person, and so on. On the other hand, there are characteristics of the performance environment that do not influence the movement characteristics of the skill. These are called *nonregulatory conditions*. For example, the color of the cup or the shape of the table the cup is on are nonrelevant pieces of information for reaching for and grasping the cup, and therefore do not influence the movements used to perform the skill.

To achieve these two important goals, the learner explores a variety of movement possibilities. Through trial and error, he or she experiences movement characteristics that are successful as well as unsuccessful, and begins to focus practice on those that are successful. In addition, because the learner has numerous problems to solve to

cognitive stage the first stage of learning in the Fitts and Posner model; the beginning or initial stage on the learning stages continuum.

associative stage the second stage of learning in the Fitts and Posner model; an intermediate stage on the learning stages continuum.

autonomous stage the third stage of learning in the Fitts and Posner model; the final stage on the learning stages continuum, also called the *automatic stage*.

"getting the idea of the movement" the learner's goal in the first stage of learning in Gentile's model; it refers to the need for the learner to establish an appropriate movement coordination pattern to accomplish the goal of the skill.

A CLOSER LOOK

Implications of Gentile's Learning Stages Model for Instruction and Rehabilitation Environments

During the First Stage

- Have the learner focus on developing the basic movement coordination pattern of the skill for both open and closed skills.
- Establish practice situations that provide opportunities to discriminate regulatory from nonregulatory characteristics.

During the Second Stage

Closed skills. In practice situations, include characteristics as similar as possible to those the learner will experience in his or her everyday world, or in the environment in which he or she will perform the skill.

Examples:

- walking on similar surfaces in similar environments
- writing with the same type of implement on the same type of surface
- shooting basketball free throws as they would occur in a game
- shooting arrows under match conditions

Open skills. In practice, systematically vary the controllable regulatory conditions of actual performance situations, while allowing naturally varying characteristics to occur as they normally would.

Examples:

- walking from one end of a hallway to the other while various numbers of people are walking in different directions and at various speeds (systematically vary the hallway size and numbers of people; allow the people to walk at any speed or in any direction they wish)
- returning volleyball serves under gamelike conditions (systematically vary the location of the serve, the offensive alignment of players, etc.; the speed and action of the ball will vary at the server's discretion)

determine how to achieve the action goal, he or she engages in a large amount of cognitive problem-solving activity. When the learner reaches the end of this stage, he or she has developed a movement coordination pattern that allows action goal achievement, but this achievement is neither consistent nor efficient. However, as Gentile (1987) described it, the learner "does have a framework for organizing an effective movement" (p. 119).

In the *second stage* the learner's goal is described as *fixation/diversification.* During this stage the learner must acquire several characteristics to continue skill improvement. First, the person must develop the capability of *adapting* the movement pattern he or she has acquired in the first stage to the specific demands of any performance situation requiring that skill. Second, the person must increase his or her *consistency* in achieving the goal of the skill. Third, the person must learn to perform the skill with an *economy of effort.*

A unique feature of the second stage in Gentile's model is that the learner's goals depend on the type of skill. More specifically, the open skill and closed skill classifications specify these goals. *Closed skills require* **fixation** of the basic movement coördination pattern acquired during the first stage of learning. This means that the learner must refine this pattern so that he or she can consistently achieve the action goal. The learner works toward developing the capability to perform the movement pattern with little, if any, conscious effort (i.e., automatically) and a minimum of physical energy. Thus, practice of a closed skill during this stage must give the learner the opportunity to "fixate" the required movement coordination pattern in such a way that he or she is capable of performing it consistently. On the other hand, *open skills require* **diversification** of the basic movement pattern acquired during the first stage of learning. An important characteristic of open skills, which differs from closed skills, is the requirement for the performer to quickly adapt to the continously changing spatial and temporal regulatory conditions of the skill. These conditions change within a performance trial as well as between trials. This means that the learner must become attuned to the critical features of the regulatory conditions and acquire the capability to modify the movement patterns to meet their constantly changing demands on the performer. As a result, rather than learning to automatically produce a specific movement pattern, the learner must acquire the capability to monitor the environmental conditions and modify the movement pattern accordingly. Thus practice of an open skill during this stage must provide the learner with experiences that will require these types of movement pattern modifications.

One aspect of the second stage of learning in Gentile's model that requires further consideration concerns the features of the acquired movement pattern that the performer must change to meet performance situation demands. Although Gentile's model indicates that fixation of the pattern is the goal of the second stage for closed skills, the performer may need to make movement pattern modifications. But, closed skill pattern modifications differ from those required for open skills. You saw some examples of these differences in the discussion of the adaptability component of our definition of learning in chapter 11. These differences relate to the distinction between invariant features and parameters of a coordination pattern, which were discussed in chapter 4. For closed skills, pattern modifications typically involve movement parameter changes rather than changes of the invariant features of the pattern itself. For example, in bowling, on the second ball of a frame the bowler is confronted with a different pattern of pins than he or she experienced with the first ball. But, rather than change the movement coordination pattern in order to bowl the ball, the bowler modifies characteristics such as location of ball release or ball speed. In golf, a ball in different types of grass or sand may require the golfer to modify his or her stance or the trajectory of the downswing, but not the invariant features of the swing itself. Similarly, situations requiring prehension may require various widths of grasp apertures or amounts of grasp force, but the basic invariant features of the reach-and-grasp action will remain consistent. However, for open skills, the performer may be required to change either the invariant features or parameters of the movement pattern. For example, if the action goal for a tennis player is to return a serve, he or she may prepare to hit a forehand groundstroke but have to change to a backhand when the serve is hit. Or, if the action goal of a pedestrian is to cross a street at an intersection, he or she may begin to walk but have to change to a run partway across because the traffic signal has changed.

Finally, it is important to note that the types of movement pattern changes required by closed and open skills involve different action planning and preparation demands for the performer. Closed skills allow the learner to plan and prepare either without any or a minimum of time constraints. However, time constraints severely limit the amount of time the performer has to plan and prepare the performance of an open skill. This difference indicates that

fixation the learner's goal in the second stage of learning in Gentile's model for learning closed skills in which learners refine movement patterns so that they can produce them correctly, consistently, and efficiently from trial to trial.

diversification the learner's goal in the second stage of learning in Gentile's model for learning open skills in which learners acquire the capability to modify the movement pattern according to environmental context characteristics.

A CLOSER LOOK

The Initial Stage of Learning to Bowl

A study by Langley (1995) provides a good illustration of the performer and performance characteristics described for the initial stage of learning in both the Fitts and Posner and the Gentile learning stages models. Langley assessed student thought processes during a beginning bowling class that met for ten weeks. He had each student complete a questionnaire at the end of each class, he took extensive observational and interpretive notes, and he interviewed the students at the beginning, middle, and end of the ten-week session.

The results of this study indicated that student thoughts focused primarily on errors in task performance. In the first week, the primary errors of concern related to lack of control of the ball, which related to inconsistency of throws and aiming problems. In the middle week, students began to describe the movement characteristics and outcomes of their throws as keys to what they needed to focus on to improve. By the end of the course, students indicated problems with consistency and accuracy of the hook ball. Consistent with expectations of learning stages models, these beginning bowlers showed evidence of an initial lack of an appropriate movement pattern to achieve the action goal, inconsistent performance, a lack of knowledge about specific components of the skill (e.g., aiming), and the development of error detection capabilities.

during practice of open skills, the performer must acquire the capability to quickly attend to the environmental regulatory characteristics that direct action as well as to anticipate changes before they actually occur.

Performer and Performance Changes across the Stages of Learning

Stages-of-learning models indicate that in each learning stage, both the person and the skill performance show distinct characteristics. In this section, we will look at a few of these characteristics. This overview has two benefits: first, it provides a closer look at the skill learning process, and second, it helps explain why instruction or training strategies need to be developed for people in different learning stages.

Changes in rate of improvement. As a person progresses along the skill learning continuum from the beginner stage to the highly skilled stage, the *rate* changes at which the person improves. Although, as figure 11.2 showed, there are four different types of performance curves representing different rates of improvement during skill learning, the *negatively accelerated pattern is more typical of skill learning* than the others. This means that early in practice, a learner usually experiences a large amount of improvement relatively quickly. But as practice continues, the amount of improvement decreases.

This change in the rate of improvement during skill learning has a long and consistent history in motor learning. In fact, in 1926 Snoddy mathematically formalized a law known as the **power law of practice.** According to this law, early practice is characterized by large amounts of improvement. However, after this seemingly rapid improvement, further practice yields improvement rates that are much smaller. Exactly how long the change in rates takes to occur depends on the skill.

Crossman (1959) reported what is today considered a classic experiment demonstrating the power law of practice. He examined how long it took cigar makers to produce a cigar as a function of how many cigars each worker had made in a career. Some workers had made 10,000 cigars, whereas others had made over 10 million. The skill itself was a relatively simple one that could be done very quickly. The first notable finding was the relationship between performance improvement and the amount of experience. Workers still showed performance improvement after seven years of experience, during which time they had made over 10 million cigars (see figure 12.2). In addition to

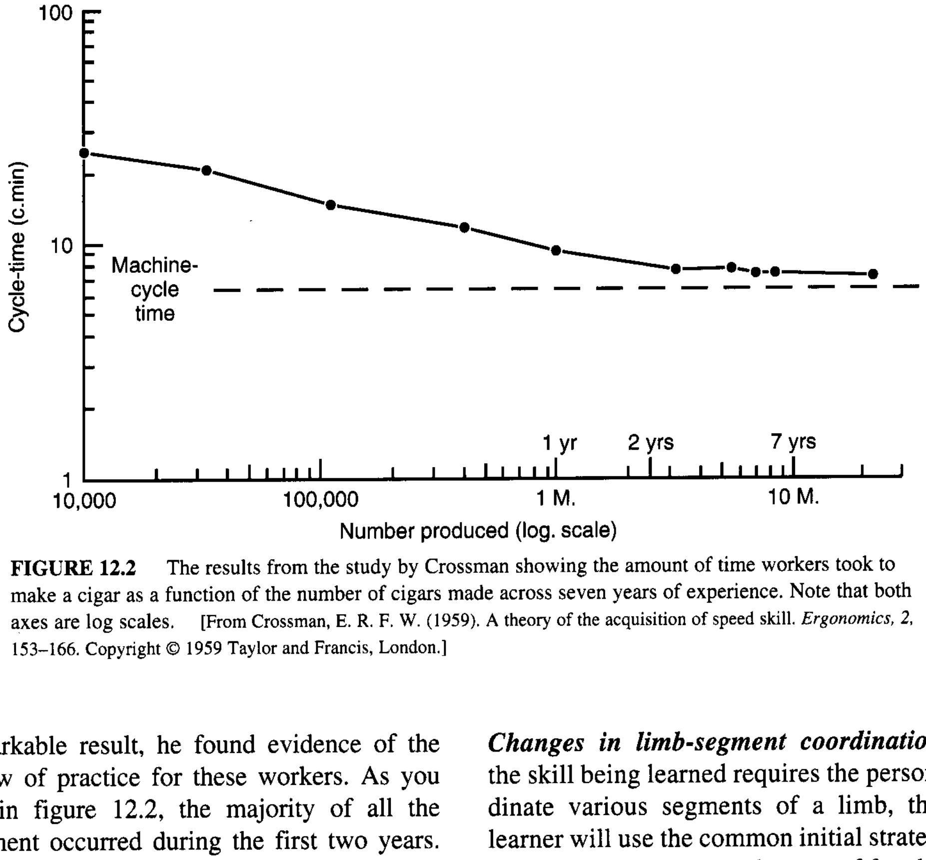

FIGURE 12.2 The results from the study by Crossman showing the amount of time workers took to make a cigar as a function of the number of cigars made across seven years of experience. Note that both axes are log scales. [From Crossman, E. R. F. W. (1959). A theory of the acquisition of speed skill. *Ergonomics, 2,* 153–166. Copyright © 1959 Taylor and Francis, London.]

this remarkable result, he found evidence of the power law of practice for these workers. As you can see in figure 12.2, the majority of all the improvement occurred during the first two years. After that, performance improvement increments were notably smaller.

The difference in rate of improvement between early and later practice is due partly to the amount of improvement possible at a given time. Initially, there is room for a large amount of improvement. The errors people make during early practice trials are large and lead to many unsuccessful attempts at performing the skill. Because many of these errors are easy to correct, the learner can experience a large amount of improvement quickly. However, as practice continues, the amount of improvement possible decreases. The errors people make later in practice are much smaller. As a result, their correction of these errors yields less improvement than they experienced earlier in practice. And certainly from the leaner's perspective, attaining notable improvement seems to take longer than it did before.

Changes in limb-segment coordination. When the skill being learned requires the person to coordinate various segments of a limb, the typical learner will use the common initial strategy of trying to control the many degrees of freedom of the limb segments by holding some joints rigid. Nikolai Bernstein, the late Russian scientist whose writings continue to influence the development of motor learning theory, described a strategy beginners use to gain control of the degrees of freedom associated with performing a complex motor skill (Bernstein, 1967; Whiting, 1984). Today, motor learning researchers refer to this

power law of practice a mathematical law describing the change in rate of performance improvement during skill learning; large amounts of improvement occur during early practice, but smaller improvement rates characterize further practice.

strategy as **freezing the degrees of freedom.** For example, suppose a beginner must perform a skill such as a racquetball forehand shot, which involves the coordination of the wrist, elbow, and shoulder joints of one arm. This means that for the arm movement component of this skill, the person needs to control three degrees of freedom. The common strategy the beginner uses to achieve this control, so that he or she can hit the ball, is to keep the wrist and elbow joints "locked" (i.e., "frozen"). This strategy makes the arm and hand move as if they were a stick, with the arm and hand segments acting as one segment. But as the person practices the skill, a freeing of the degrees of freedom emerges as the "frozen" joints begin to become "unfrozen" and operate in a way that allows the arm and hand segments to function as a multisegment unit. This new unit eventually demonstrates characteristics of a *functional synergy,* which means the individual arm and hand segments work together in a cooperative way to enable optimal performance of the skill. It is interesting to note that Southard and Higgins (1987) reported evidence demonstrating this kind of coordination development for the arm movement component of the racquetball forehand shot. They showed that a primary benefit of the development of the functional synergy of the arm segments was an increase in racquet velocity at ball impact.

Researchers have demonstrated similar coordination development characteristics for several other skills. For example, Anderson and Sidaway (1994) showed that when beginning soccer players initially tried to kick a ball properly, they limited the movements of their hip and knee joints. The problem with this strategy is that it limits the velocity that can be generated by the hip joint, because the player cannot use the knee joint effectively. With practice, however, players' kicking velocity increased, as their hip and knee joints acquired greater freedom of movement and increased functional synergy.

In a final example, note that these coordination changes are not limited to sports skills or to people acquiring new skills. Stroke patients going through physical therapy to help them move from sitting to standing and then to sitting again show coordination development characteristics similar to those of people acquiring a new skill (Ada, O'Dwyer, & Neilson, 1993). In this experiment, recovering stroke patients progressed from being able to sit-stand-sit without assistance one time to being able to perform this sequence three times in a row in 10 sec. It is noteworthy that the coordination between the hip and the knee joints showed marked improvement changes as the patients progressed, demonstrating the development of the functional synergy required for these joints to allow unaided standing.

Changes in altering a preferred coordination pattern. Because we have learned to perform a variety of motor skills throughout our lives, we have developed preferred ways of moving. In fact, each of us has developed a rather large repertoire of movement patterns that we prefer to use. When confronted with learning a new skill, we often determine that it resembles a skill we already know how to perform. As a result, we typically begin practicing the new skill using movement characteristics similar to those of the skill we already know. For example, it is common for an experienced baseball player to use a swing resembling baseball batting when he or she first practices hitting a golf ball.

When a person is learning a new skill that requires altering an established coordination pattern, an interesting transition from old to new pattern occurs. The experiment by Lee, Swinnen, and Verschueren (1995) that we discussed in chapter 11 provides a good example of this change. Recall that participants had to lean to bimanually move two levers simultaneously in a 90-degree out-of-phase arm movement relationship in order to draw ellipses on the computer monitor. Figure 11.4 showed that when they first were confronted with this task, the participants' preferred way of coordinating their arms was to move both arms at the same time, producing diagonal patterns. The influence of this preferred movement pattern remained

A CLOSER LOOK

Controlling Degrees of Freedom as a Training Strategy in Occupational Therapy

A case study of a thirty-four-year-old hemiplegic woman who had suffered a stroke demonstrates how a therapist can use an understanding of the degree-of-freedom problem to develop an occupational therapy strategy (Flinn, 1995). To increase impaired left-arm strength and function during the first two months of outpatient therapy, the therapist engaged the patient in using the impaired arm to perform several functional tasks for which the degrees of freedom were restricted. To achieve this, the therapist decreased the number of joints involved in the task by stabilizing or eliminating some joints and decreasing the amount of movement of the limb against gravity. For example, the patient used the impaired arm to lock her wheelchair brakes, dust tables, and provide stability while she stood and brushed her teeth using her sound arm. During the next two months, as the patient's left-arm use improved, the therapist increased the degrees of freedom by requiring the control of more joints. For example, initially the patient simply had pushed silverware from the counter into the drawer; now the patient grasped the objects from the counter, lifted them, and placed them in the drawer. Finally, the therapist again increased the degrees-of-freedom demands a couple of months later. Now the treatment focused specifically on the everyday multiple degrees-of-freedom tasks the patient would have to perform at her regular workplace.

for more than sixty practice trials. Participants did not produce the new coordination pattern consistently until they had performed 180 practice trials. Instability characterized the coordination patterns they produced on trials between these two demonstrations of stable patterns.

The Lee et al. experiment demonstrates several things. First, it shows that people approach skill learning situations with distinct movement pattern biases that they may need to overcome to achieve the goal of the skill to be learned. Second, it is possible for people to overcome these biases, but often this takes a lot of practice (the actual amount varies among people). Finally, an observable pattern of stability-instability-stability characterizes the transition between production of the preferred movement pattern and production of the goal pattern. The initially preferred and the newly acquired goal movement patterns are distinguished by unique but stable kinematic characteristics over repeated performances. However, during the transition period between these stable patterns, the limb kinematics are very irregular or unstable.

People who provide skill instruction should note that this transition period can be a difficult and frustrating time for the learner. The instructor or therapist who is aware of this can be influential in helping the person work through this transition stage. One helpful strategy is providing extra motivational encouragements to keep the person effectively engaged in practice.

Changes in muscles used to perform the skill. If practicing a skill results in coordination changes, we should expect a related change in the muscles a person uses while performing the skill. EMG patterns produced while people practiced skills have shown that early in practice a person uses his or her muscles inappropriately. Two characteristics are particularly noteworthy. First, more muscles than are needed commonly are involved. Second, the timing of the activation of the involved muscle

freezing the degrees of freedom a common initial strategy of beginning learners to control the many degrees of freedom associated with the coordination demands of a motor skill; the person holds some joints rigid (i.e., "freezes" them) while performing the skill.

A CLOSER LOOK

Muscle Activation Changes during Dart-Throwing Practice

An experiment by Jaegers et al. (1989) illustrates how the sequence and timing of muscle activation reorganizes as a person practices a skill. Individuals who were inexperienced in dart throwing made forty-five throws at a target on each of three successive days. Several arm and shoulder muscles were monitored by EMG.

The three muscles primarily involved in stabilizing the arm and upper body were the anterior deltoid, latissimus dorsi, and clavicular pectoralis. On the first day, these muscles erratically activated both before and after the dart release. But at the end of the last day, these mucles followed a specific sequence of activation initiation. The clavicular pectoralis and anterior deltoid muscles became active approximately 40 to 80 msec prior to the dart release and turned off at release. The latissimus dorsi became active just before the release and remained active for 40 msec after release. Then, the anterior deltoid became active again.

The primary muscle involved in producing the forearm-extension–based throwing action was the lateral triceps. During the initial practice trials, this muscle initiated activation erratically, before and after dart release. But by the end of the third day, it consistently initiated activation approximately 60 msec prior to dart release and remained active until just after release.

groups is incorrect. As a person continues to practice, the number of muscles involved decreases so that eventually a minimal number of muscles needed to produce the action are activated, and the timing of when the involved muscles are activated becomes appropriate.

Researchers have provided evidence showing these types of change during practice for a variety of physical activities. For example, muscle activation changes have been demonstrated for sport skills such as the single-knee circle mount on the horizontal bar in gymnastics (Kamon & Gormley, 1968), ball throwing to a target (Vorro, Wilson, & Dainis, 1978), and dart throwing (Jaegers et al., 1989). Also, researchers have shown muscle activation differences resulting from practice in laboratory tasks, such as complex, rapid arm movement and manual aiming tasks (Schneider et al., 1989), as well as simple, rapid elbow flexion tasks (Gabriel & Boucher, 1998), and arm-extension tasks (Moore & Marteniuk, 1986).

The change in muscle use that occurs while a person learns a skill reflects a *reorganization of the motor control system* as that skill is acquired. As Bernstein (1967) first proposed, this reorganization results from the need for the motor control system to solve the degrees-of-freedom problem it confronts when the person first attempts the skill. By structuring muscle activation appropriately, the motor control system can take advantage of physical properties of the environment, such as gravity or other basic physical laws. By doing this, the motor control system reduces the amount of work it has to do and establishes a base for successful skill performance.

Changes in energy use. Because the performer and performance changes we have described in the preceding sections occur as a result of practicing a skill, we can reasonably expect that the amount of energy a person uses while performing the skill should change with practice as well. Although there has been little empirical study of this effect, evidence supports this expectation. Economy of movement refers to minimizing the energy cost of performing a skill. Beginners expend a large amount of energy (have a high energy cost), whereas skilled performers perform more efficiently, with minimum expenditure of energy.*

Several energy sources have been associated with performing skills. One is the *physiological*

*Note that many prefer the term *economy* to *efficiency;* see Sparrow and Newell (1998).

energy involved in skilled performance; researchers identify this by measuring the amount of oxygen a person uses while performing a skill. They also determine physiological energy use by measuring the caloric cost of performing the skill. People also expended *mechanical energy* while performing; scientists determine this by dividing the work rate by the metabolic rate of the individual. As we learn a skill, changes in the amount of energy we use occur for each of these sources. The result is that we perform with greater efficiency; in other words, our energy cost decreases as our movements become more economical.

Scientists have been accumulating research evidence only recently to support the widely held assumption that energy use decreases as a result of practicing a skill. For example, *oxygen use* decreased for people learning to perform on a complex slalom ski simulator in twenty-min practice sessions over a period of five days (Durand et al., 1994). Sparrow (Sparrow & Irizarry-Lopez, 1987; Sparrow & Newell, 1994) demonstrated that oxygen use, heart rate, and *caloric costs* decrease with practice of a motor skill for persons learning to walk on their hands and feet (creeping) on a treadmill moving at a constant speed. And Heise (1995; Heise & Cornwell, 1997) showed *mechanical efficiency* to increase as a function of practice for people learning to perform a ball-throwing task.

Changes in achieving the kinematic goals of the skill. Kinematic characteristics define the spatial and temporal features of performing a skill. Skilled performance has certain displacement, velocity, and acceleration limb-movement-pattern goals. As a person practices a skill, he or she not only becomes more successful in achieving these goals, but also acquires these kinematic goals at different times during practice, although in the same sequence. Displacement is the first kinematic goals persons achieve, indicating that spatial characteristics of a skill are the first ones people successfully acquire. The next goal people achieve is velocity; this is followed by acceleration. The instructional significance of this progression of kinematics is that it suggests the importance of focusing on spatial features of a skill first, and then progressing to the more temporal features.

Marteniuk and Romanow (1983) provided the best demonstation of this systematic progression of kinematic goal acquisition in an experiment that was briefly introduced in chapter 11. Participants practiced moving a horizontal lever back and forth to produce a complex displacement pattern (shown in figure 11-3). During 800 trials of practice, they became increasingly more accurate and consistent at producing the criterion pattern. An evaluation of the kinematic performance measures showed that the participants first achieved accuracy and consistency with the displacement characteristics. Then they acquired the velocity and finally the acceleration characteristics as practice progressed.

Changes in visual attention. Because vision plays a key role in the learning and control of skills, it is interesting to note how the use of vision changes as a function of practicing a skill. Because we discussed most of these changes at length in chapter 6, we will mention them only briefly here. Beginners typically look at too many things; this tendency leads them frequently to direct their visual attention to inappropriate environmental cues. As a person practices a skill, he or she directs visual attention toward sources of information that are more appropriate for guiding his or her performance. In other words, the person gains an increased capability to direct his or her vision to the regulatory features in the environment that will provide the most useful information for performing the skill. Also, people get better at appropriately directing their visual attention earlier during the time course of performing a skill. This timing aspect of directing visual attention is important because it increases the time available in which the person can select and produce an action required by the situation.

Changes in conscious attention when performing a skill. According to the Fitts and Posner learning stages model, early in practice the learner consciously thinks about almost every part of performing the skill.

A CLOSER LOOK

Driving Experience and Attention Demands of Driving a Standard-Shift Car

Shinar, Meir, and Ben-Shoham (1998) used a dual-task procedure to determine the influence of years of driving experience on the attention demands for driving a standard shift car. They asked forty licensed drivers (ages eighteen to sixty-six years) to drive their own manual or automatic transmission cars through a 5-km route through downtown Tel Aviv. The route involved streets with multiple lanes, many intersections, many traffic signs, heavy traffic, and many pedestrians and pedestrian crossings. The secondary task involved the drivers observing traffic signs and verbally reporting each sign that indicated "Slow—Children on the Road" and "No Stopping."

The results showed that the experienced drivers (median = eight years of experience) of either the manual or automatic transmission cars detected similar percentages of the two signs. However, the novice drivers (median = one and one-quarter years of experience) of manual transmission cars detected lower percentages of the signs than those who drove automatic transmission cars. Thus, driving experience led to a reduction in the attention demanded by the action of gear shifting to such an extent that driving a manual transmission car in heavy traffic became similar to the attention demanded when driving an automatic transmission car.

But as the person practices the skill and becomes more proficient, the amount of conscious attention he or she directs to performing the skill itself diminishes to the point at which he or she performs it almost automatically.

We see an everyday example of this change in the process of learning to shift gears in a standard shift car. If you have learned to drive a standard shift car, you undoubtedly remember how you approached shifting gears when you first learned to do so. Each part of the maneuver required your conscious attention. You thought about each part of the entire sequence of movements: when to lift off the accelerator, when to push in the clutch, how to coordinate your leg movements to carry out these clutch and accelerator actions, when and where to move the gear shift, when to let out the clutch, and finally, when to depress the accelerator again. But what happened as you became a more experienced driver? Eventually, you performed all these movements without conscious attention. In fact, you undoubtedly found that you were able to do something else at the same time, such as carry on a conversation or sing along with the radio. You would have had great difficulty doing any of these things while shifting when you were first learning to drive.

Changes in error detection and correction capability. Another performance characteristic that improves during practice is the capability to identify and correct one's own movement errors. An individual can use this capability either during or after the performance of the skill, depending on the time constraints involved. If the movements are slow enough, a person can correct or modify an ongoing movement while the action is occurring. For example, if a person grasps a cup and brings it to the mouth to drink from it, he or she can make some adjustments along the way that will allow him or her to accomplish each phase of this action successfully. However, for rapid movements, such as initiating and carrying out a swing at a baseball, a person often cannot make the correction in time during the execution of the swing, because the ball has moved past a hittable location by the time the person makes the correction. For both types of skills, performers can use errors they detect during their performance to guide future attempts.

Expertise

If a person practices a skill long enough and has the right kind of instruction, he or she eventually may become skilled enough to be an *expert*. On the

A CLOSER LOOK

A Summary of Performer and Performance Changes across the Stages of Learning

• *Rate of improvement*	The amount of improvement decreases (*power law of practice*)
• *Limb-segment coordination*	Coordination patterns change from a "freezing" of limb segments to the segments working together as a functional synergy
• *Altering an old or preferred coordination pattern*	Coordination patterns change from the old pattern to a transitional state of no evident pattern to a new pattern
• *Muscles involved*	The number of muscles involved decreases and the timing pattern of muscle group activation becomes appropriate for the action situation
• *Energy use/movement efficiency*	The amount of energy used decreases; movement efficiency increases
• *Achievement of kinematic goals*	Spatial-to-temporal goals sequence
• *Visual attention*	Increasingly becomes directed to more appropriate sources of information
• *Conscious attention*	Amount of conscious attention to movement characteristics reduces
• *Error detection and correction*	Capability increases to detect and correct performance errors

learning stages continuum we presented earlier in this discussion (figure 12.1), the expert is a person who is located at the extreme right end. This person is in an elite group of people who are exceptional and outstanding performers. Although motor skill expertise is a relatively new area of study in motor learning research, we know that experts have distinct characteristics. Most of our knowledge about experts in the motor skills domain relates to athletes, dancers, and musicians. Although they are in seemingly diverse fields, experts in these skill performance areas have some similar characteristics. Some of these will be examined next.

Amount and type of practice leading to expertise. In an extensive study of experts from a diverse number of fields, Ericsson, Krampe, and Tesch-Romer (1993) reported that expertise in all fields is the result of *intense practice for a minimum of ten years.* Critical to achieving expertise is not only the length of time in which the person practices intensely, but also the type of practice. According to Ericsson and his colleagues, the specific type of intense practice a person needs to achieve expertise in any field is *deliberate practice.* During this type of practice, the person receives optimal instruction, as well as engages in intense, worklike practice for hours each day. As the person develops toward expertise, he or she begins to need personalized training, or supervision of the practice regime.

A characteristic of expertise that emerges from the length and intensity of practice required to achieve expertise in a field is this: *expertise is domain specific* (see Ericsson & Smith, 1991). This means that characteristics of experts are specific to the field in which they have attained this level of success. There is little transfer of the capabilities in the field of expertise to another field in which the person has no experience.

Experts' knowledge structure. A notable characteristic common to expert skill performers is that they know more about an activity than nonexperts do. More important, this expert knowledge is structured quite differently as well. Research investigating experts in a number of diverse skills, such as chess, computer programming, bridge, and basketball, has shown that the expert has developed his or her

A CLOSER LOOK

Experts Compared to Novices: Vision

Bruce Abernethy, one of the world's leading researchers on the issue of expertise as it relates to the use of vision in the performance of motor skills, summarized some primary research findings in an article published in 1999 in the *Journal of Applied Sport Psychology.* The following are some of his key points about the comparison between experts and novices in their use of vision in performance situations in which there is a very brief window of time to detect and use visual information, such as hitting a pitched baseball or returning a racquetball serve.

No Differences

- General vision measures (e.g., visual acuity) and nerve function measures (e.g., nerve conduction velocity) *Experts' superior performance relates more to the superior use of visual information.*
- Visual search patterns may or may not differ *Experts exhibit superior use of visual information even when search patterns are similar.*

Differences

- Experts are faster and more accurate in recognizing patterns in their own skill domain *"Patterns" refer to coordination patterns related to an action and to patterns involving several people.*
- Experts detect and use important action-directing cues faster *The result is better anticipation and faster implementation of a required action.*

knowledge about the activity into more organized concepts and is better able to interrelate the concepts. The expert's knowledge structure also is characterized by more decision rules, which he or she uses in deciding how to perform in specific situations. Additionally, because of the way the knowledge is structured, the expert can remember more information from one observation or presentation.

The benefit of these knowledge structure characteristics is that they enable the expert to solve problems and make decisions faster and more accurately than a nonexpert can, and to adapt to novel environments more easily. For example, an expert basketball player bringing the ball down the floor can look at one or two players on the other team and know which type of defense the team is using; he or she then can make decisions about whether to pass, dribble, or shoot. The beginner would need to take more time to make these same decisions because he or she would need to look at more players to obtain the same information.

Experts' use of vision. When experts perform an activity, they use vision in more advantageous ways than nonexperts do. We discussed many of these characteristics in chapters 6 and 9. For example, experts search their environment faster, give more attention to this search, and select more meaningful information in less time. Also, experts do not need as much environmental information for decision making, primarily because they "see" more when they look somewhere. Undoubtedly due in part to their superior visual search and decision-making capabilities, experts can use visual information better than nonexperts to anticipate the actions of others. And experts recognize patterns in the environment sooner than nonexperts do. Experts achieve these vision characteristics after many years of experience performing a skill; studies have shown the characteristics to be a function more of experience than of better visual acuity or eyesight.

SUMMARY

Learning is a process that involves time and practice. As an individual moves from being a beginner in an activity to being a highly skilled performer, he or she progresses through distinct, although continuous, stages. Two different models were discussed to describe these stages. Fitts and Posner proposed that the learner progresses through three stages: the cognitive, the associative, and the autonomous stages. Gentile proposed two stages, which she identified in terms of the goal of the learner. The learner's goal in the first stage is "getting the idea of the movement." In the second stage, the learner's goal is fixation or diversification for closed and open skills, respectively.

As people progress through the learning stages, distinct performer and performance changes are notable. We have discussed several here: changes in the rate of improvement, coordination pattern characteristics, the muscles involved in performing the skill, energy use and movement efficiency, the achievement of the kinematic goals of the skill, visual attention, conscious attention, and the learner's capability of detecting and correcting errors.

Finally, we discussed the expert end of the learning continuum. Experts are characterized by exceptional performance. They take a minimum of ten years of intense practice to achieve expertise. These highly skilled people have common performance characteristics in their use of vision and in their knowledge structures, which provide the basis for their exceptional performance capability.

RELATED READINGS

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STUDY QUESTIONS

1. Describe some characteristics of learners as they progress through the three stages of learning proposed by Fitts and Posner.

2. How does Gentile's learning stages model differ from the Fitts and Posner model? How does her model relate specifically to learning open and closed skills?

3. Describe four performer or performance changes that research has shown to occur as a person progresses through the stages of learning a motor skill.

4. Describe what an expert is and how a person can become an expert motor skill performer. What are some characteristics that distinguish an expert from a nonexpert?