CHAPTER 12

# The Stages of Learning

*Concept: Distinct performance and performer characteristics change during skill learning.*

After completing this chapter, you will be able to

- Describe characteristics of learners as they progress through the stages of learning as proposed by Fitts and Posner, Gentile, and Bernstein
- Describe several performer- and performance-related changes that occur as a person progresses through the stages of learning a motor skill
- Discuss several characteristics that distinguish an expert motor skill performer from a nonexpert

## 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. In other words, the expert has difficulty behaving or thinking like a beginner. 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 number 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. Now, recall what you thought about after you had considerable practice and had become reasonably proficient at serving. You probably did not continue to think about all the specific elements each time you served.

In the rehabilitation clinic, 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.

**Application Problem to Solve** Select a motor skill that you perform well for recreational or sports purposes. Think back to when you first learned to perform this skill. Try to remember how successful you were and what you had the most difficulty doing, as well as what you thought about while performing the skill and what was notable about your performance. Then recall how your performance and your approach to performing the skill changed as you became more skillful. What characteristics of your performance changed and how did they change?

Learning how to ski involves distinct stages of learning as one progresses from being a beginner to a highly skilled performer.

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## 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 and will elaborate on Bernstein's ideas about learning throughout the chapter. It is important to note that each of these models presents performer and performance characteristics associated with each stage of learning that we will refer to throughout the chapters that follow. An excellent way to synthesize the information that follows is to relate learning a new skill to solving a movement problem. This helpful analogy from Bernstein provides important insights into what changes are likely to occur as learners become more skillful and what practitioners can do to facilitate those changes.

## THE FITTS AND POSNER THREE-STAGE MODEL

Paul Fitts, to whom you were introduced in chapter 7, and Michael Posner presented the acknowledged classic learning stages model in 1967. Their model continues to be referred to in textbooks and 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[1] focuses on cognitively oriented problems related to what to do and how to do it. 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 numerous 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 transition into this stage occurs after an unspecified amount of practice and performance improvement. The cognitive activity that characterized the cognitive stage changes at this stage, because the person now attempts to *associate*

[1]The term *beginner* is used here and throughout the following chapters to refer to a person who is beginning to learn, or relearn, a skill.

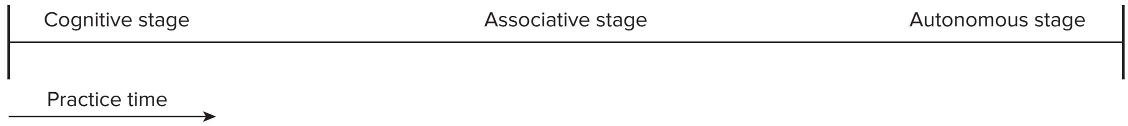


**FIGURE 12.1** The stages of learning from the Fitts and Posner model placed on a time continuum.

specific environmental cues with the movements required to achieve the goal of the skill. The person makes fewer and smaller errors since he or she has acquired the basic fundamentals or mechanics of the skill, although room for improvement is still available. Because improvements continue, 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 decreases, and 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 final **autonomous stage** of learning. Here the skill has become almost *automatic,* or habitual. People in this stage do not consciously think about their movements 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 or walking. 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 many of their own errors and make the proper adjustments to correct them, although he or she will be unaware of many movement details because these details are now controlled automatically. 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. In the final section of this chapter we will examine Ericsson's (1998) unique interpretation of how experts negotiate the autonomous stage of learning.

It is important to think of the three stages of the Fitts and Posner model as parts of a continuum of practice time, as depicted in figure 12.1. The amount of time a person will be in each stage depends on the skill being learned and the practice conditions, as well as the characteristics of the person. Individual differences can influence one person to spend more time in a specific stage than another person. Similarly, the same person could spend more time in one stage for one type of skill than for another type of skill. It is also important to note that people who are learning a skill do not make abrupt shifts from one stage to the next, though qualitative leaps in performance are not uncommon within each stage (Anderson, 2000; Bernstein, 1996). There is typically 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 this discussion, the beginner and the skilled performer have distinct characteristics that we can observe and need to understand.

**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.*

**LAB LINKS**

Lab 12a in the Online Learning Center Lab Manual for chapter 12 provides an opportunity for you to learn a new motor skill and experience a progression through some learning stages.

## GENTILE'S TWO-STAGE MODEL

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

### Initial Stage of Learning

In what Gentile labeled the *initial stage,* the beginner has *two important goals* to achieve. One is to acquire a *movement pattern* that will allow some degree of success at achieving the action goal of the skill. This means that the beginner must develop movement characteristics that match the regulatory conditions of the environmental context in which the skill is performed. Recall from the discussion of Gentile's taxonomy of motor skills in chapter 1 of this text that the term *regulatory conditions* refers to those characteristics of the environmental context to which movement characteristics must conform if the action goal is to be accomplished. For example, if a person is beginning to rehabilitate his or her prehension skills, he or she must focus on developing the arm and hand movement characteristics that match the physical characteristics associated with the object to be grasped. If, in the prehension example, the person must reach and grasp a cup that is on a table, the regulatory conditions include the size and shape of the cup, location of the cup, amount and type of liquid in the cup, and so on.

The second goal of the beginner is to learn to *discriminate between regulatory and nonregulatory conditions* in the environmental context in which he or she performs the skill. Unlike regulatory conditions, the *nonregulatory conditions* are those characteristics of the performance environment that have no influence or only an indirect influence on the movement characteristics required to achieve an action goal. To continue with the example of reaching and grasping a cup, 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 beginner explores a variety of movement possibilities. Through trial and error, he or she experiences movement characteristics that match and do not match requirements of the regulatory conditions. In addition, because the learner must solve numerous problems to 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 pattern that allows some action goal achievement, but this achievement is neither consistent nor efficient. As Gentile (2000) described it, "Although the learner now has a general concept of an effective approach, he or she is not skilled. The action-goal is not achieved consistently and the movement lacks efficiency" (p. 149).

### Later Stages of Learning

In the second stage, called the *later stages* by Gentile, the learner works to achieve *three important goals.* First, the person must develop the capability of *adapting* the movement pattern 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.* We will next discuss each of these three characteristics.

***Fixation and diversification as learning goals.*** A unique feature of the second stage in Gentile's model is that the *learner's movement goals depend on the type of skill.* More specifically, the open skill

## A CLOSER LOOK

### Gentile's Learning Stages Model Applied to Instruction and Rehabilitation Environments

**During the Initial Stage**

- Have the learner focus on achieving the action goal, which will allow the development of the basic movement coordination pattern of the skill.
- Establish practice situations that provide opportunities to discriminate regulatory from nonregulatory characteristics.

**During the Later 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:*

- reaching, grasping, and drinking from a variety of sizes and shapes of containers
- 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 numbers of people; allow the people to walk at any speed or in any direction they wish)

and closed skill classifications specify these goals. *Closed skills require* **fixation** of the basic movement coordination 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 differ from closed skills in this way, is the requirement for the performer to quickly adapt to the continuously 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 regulatory conditions and acquire the capability to modify movements to meet their constantly changing demands on the performer. As a result, the learner must acquire the capability to automatically monitor the environmental context and modify the movements accordingly. Thus, practice of an open skill during this stage must provide the learner with experiences that will require these types of movement modifications.

**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.

***Movement modification requirements.*** It is important to note that the types of movement 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 with 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 during practice of open skills, the performer must acquire the capability to quickly attend to the environmental regulatory conditions as well as to anticipate changes before they actually occur.

## BERNSTEIN'S DESCRIPTION OF THE LEARNING PROCESS

In a chapter titled "On Exercise and Skill" republished in a book titled *On Dexterity and Its Development* (1996), Bernstein provided one of the most comprehensive descriptions of how difficult it is to acquire a new skill. He proposed that learning a skill is similar to solving a problem, and likened the process of solving the problem to staging a play, in which the *first* decision is to determine which level in the motor control system will take the leading role in the performance. Bernstein argued that the level of Actions typically takes the lead, directing other levels that have as their responsibility coordinating movements with external space, organizing muscular synergies, and regulating muscle tone. The *second* phase involves developing a plan or strategy to approach the problem (specifying how the skill will look from the outside) and recruiting and assigning roles to the lower levels of the motor control system. The *third* phase involves identifying the most appropriate sensory corrections (specifying how the skill should feel from the inside). During these initial *planning* phases, the learner may consciously direct attention to the numerous details associated with controlling the movement.

In the *fourth* phase, the corrections are handed over to the background levels and so are typically engaged without conscious awareness. Bernstein thought that the background corrections were close to independent motor skills (automatisms) in their own right and so capable of being used in more than one movement, though often only after modification. Automatization of the skill becomes complete when the background level is mature enough to break free from the support provided by the leading level. It represents an *ah ha!* moment; a qualitative leap forward. The *next phase* is gradual and involves achieving a harmony among the background corrections. Compared to the staging of a play, if the earlier phases were spent on assigning roles to the players, rewriting the script, and learning the lines by heart, then this phase would be viewed as rehearsals in which all of the elements must mutually adjust to each other. The learner may experience delays, hesitations, and even regressions in skill during this phase; however, such temporary setbacks are typically followed by major leaps forward in automatization.

The final two phases involve *standardization* and *stabilization*. Standardization involves the reaction forces among the joints often taking the place of sensory corrections in counteracting external forces that would otherwise interfere with the movement. In many skills, this change leads to a form of dynamic stability that is accompanied by an enormous reduction in effort. The *final phase* is the stabilization of the skill against a disturbance or a change in the external conditions. The learner is now able to cope with various disruptions and prevent the skill from becoming deautomatized.

The process that Bernstein describes is clearly complex and arduous. *Repetitions of a movement or action are necessary to solve the motor problem many times and to find the best way of solving it* given the infinite number of external conditions one might encounter and the fact that movements are never reproduced exactly. To solve the problem consistently, under a wide variety of conditions, and with an economy of effort, the learner must experience as many modifications of the task as possible. Appropriate practice is thus viewed as a form of *repetition without repetition*. To quote Bernstein (1996) directly, "The point is that during a correctly organized exercise, a student is repeating many times, *not the means for solving* a given motor problem, but *the process of its solution*, the changing and improving of the means" (p. 205).

## 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* at which the performance improves changes. Although, as you saw in figure 11.2 in chapter 11, there are four different types of performance curves representing different rates of improvement during skill learning, the *negatively accelerated pattern is more typical of motor 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 the classic experiment demonstrating the power law of practice. He examined the amount of time it took cigar makers to produce one cigar as a function of how many cigars each worker had made since beginning work at the factory. 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 some performance improvement after seven years of experience, during which time they had made over 10 million cigars (see figure 12.2). In addition to 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.

In a more recent demonstration of the power law of practice, Chen, Liu, Mayer-Kress, and Newell (2005) had participants learn to perform a pedalo locomotion task. The pedalo is a commercially available device that has two plastic pedals, on which a person stands; these are connected to four wheels by two iron rods that act like cranks and go through the pedals. The task is to stand on the plastic pedals and move them with the feet so that the wheels move forward or backward. The

**LAB LINKS**

Lab 12b in the Online Learning Center Lab Manual for chapter 12 provides an opportunity for you to compare characteristics of novices and experts performing the same skill.

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

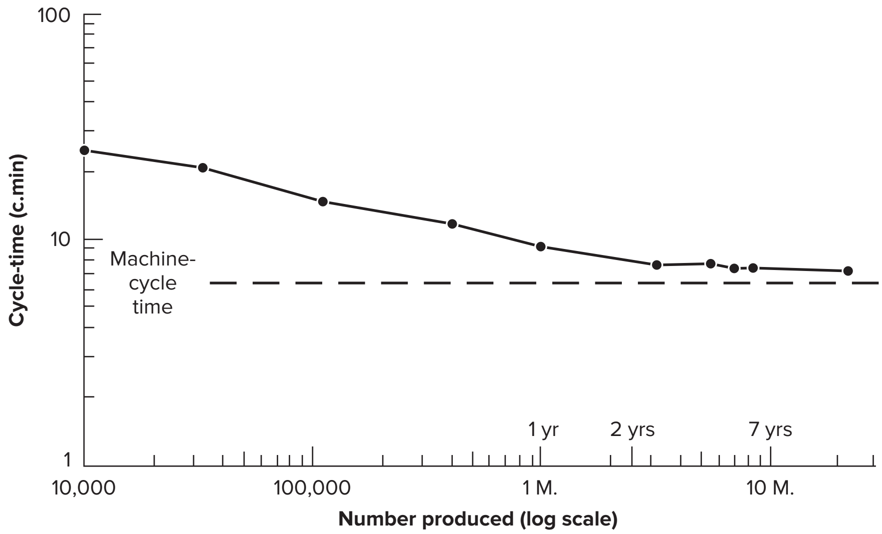


**FIGURE 12.2** The results from the study by Crossman showing the amount of time workers took to make a cigar as a function of the number of cigars made across seven years of experience. Note that both axes are log scales. *Source:* From Crossman, E. R. F. W. (1959). A theory of the acquisition of speed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

task involves dynamic balance and requires coordination of the torso and limbs to keep the pedalo moving. For the experiment, the participants' goal was to achieve the fastest movement time (MT) they could while moving as smoothly as possible for a specified distance. They practiced the task for fifty trials a day for seven days. The results showed that MT decreased during practice in a pattern that was consistent with the power law of practice. This means that MT decreased rapidly on the first two days, but then decreased very little for the remaining practice trials.

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 a smaller amount of improvement than they experienced earlier in practice. And certainly from the learner's perspective, attaining notable improvement seems to take longer than it did before.

### Changes in Movement Coordination

In the discussion in chapter 5, you saw that to perform a complex motor skill (i.e., one that involves several limbs or limb segments), the motor control system must solve the *degrees of freedom problem.* Recall that when we relate this problem to the muscles and joints, it concerns the need to constrain the many degrees of freedom of movement associated with the muscles and joints involved in performing the skill. For the beginning learner, solving this problem is a critical part of the learning process. In fact, solving this problem underlies the achievement of an important goal for the learner in Gentile's initial stage of learning, which is to acquire a movement coordination pattern that typically results from attaining some success at achieving the action goal.

Bernstein, whom we noted in chapter 5 first identified this problem, described a strategy beginners typically use to gain initial control of the many degrees of freedom associated with performing a complex motor skill (Bernstein, 1967; Whiting, 1984). This strategy, which researchers now refer to as **freezing the degrees of freedom,** involves holding some joints rigid (i.e., "freezing" them) and/or coupling joint motions together in tight synchrony while performing the skill. For example, suppose a beginner must perform a skill such as a racquetball or squash forehand shot, which, at the joint level, involves the coordination of three degrees of freedom for the arm used to hit the ball: the wrist, elbow, and shoulder joints. A common strategy the beginner uses to control these joints 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.

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 that 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 strategy and coordination development for the arm movement 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 forcefully, 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 foot because the knee joint and shank are unable to exploit the momentum of the thigh. With practice, however, players' kicking velocity increased, as their hip and knee joints acquired greater freedom of movement and increased functional synergy. These results were described in figure 5.2, which portrayed the pre- and post-practice knee-and-hip relationship results from this study as an example of a graphic representation of coordination patterns.

With continued practice, the learner ultimately develops a coordination pattern that is dynamically stable and more economical. Economy increases because the coordination pattern now exploits passive forces, like gravity, inertia, and reactive forces, to meet the task demands. Consequently, the contribution of active muscular forces is diminished.

These kinds of 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. As the patients progressed, the coordination between the hip and the knee joints showed marked improvement which demonstrated the development of the functional synergy required for these joints to allow unaided standing.

The development of independent walking represents an excellent example of how the coordination pattern can exploit passive forces and minimize energy costs. During the stance phase of walking, the center of mass (COM) vaults over a relatively rigid leg like an inverted pendulum. There is an exchange between the potential energy and the

**freezing the degrees of freedom** 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) and/or couples joint motions together in tight synchrony while performing the skill.

## 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 degrees 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.

- Initially, the therapist decreased the number of joints involved by restricting the movement of certain joints and decreasing the amount of movement required of the limb against gravity.

  *Example:* The patient used the impaired arm to apply her wheelchair brakes, dust tables, and provide postural stability as she brushed her teeth using her nonimpaired arm.

- During the next two months, as the patient's use of her left arm improved, the therapist increased the degrees of freedom by requiring the use of more joints to perform tasks.

  *Example:* In the initial therapy period, the patient simply pushed silverware from the counter into the drawer; now she grasped each object from the counter, lifted it, and placed it in the drawer.

- Finally (a couple of months later), the therapist again increased the degrees of freedom demands by focusing treatment specifically on the everyday multiple degrees of freedom tasks the patient would have to perform at her regular workplace.

kinetic energy of the COM during each step, with potential energy being highest when the COM is at its highest point and kinetic energy being highest when the COM is at its lowest point. Though adults are very good at recovering mechanical energy during walking, Ivanenko et al. (2004) showed that the percentage of mechanical energy recovery in toddlers was about 50 percent of what it was in older children and adults. This finding suggests that young walkers must learn the appropriate intersegmental coordination to exploit the pendulum mechanism to recover mechanical energy during walking. Patients who have had one or both legs amputated and who are learning to walk with lower limb prostheses for the first time are likely to encounter the same problems as the toddler learning to walk. Because the stiffness of the prosthetic limb, particularly the ankle-foot prosthesis, will be very different from the stiffness of the anatomical limb, the patient will likely need some time to learn how to exploit the energy storing and releasing elements that are built into the prosthesis.

An important feature of coordination changes during learning is their relationship to observed performance. Recall that according to Gentile's stages of learning model the beginner works on achieving action goal success, which is typically seen in performance outcome measures (e.g., increasing the number of free throws made with a basketball). As the person improves his or her performance in terms of action goal achievement, there are underlying coordination changes occurring. During the initial stage of learning these coordination changes establish an "in-the-ballpark" but unstable and inefficient movement pattern. It is during the later stages of learning that the movement pattern stabilization process occurs to allow consistent and efficient performance of the skill.

### Changes in How Degrees of Freedom Are Controlled

Despite its popularity, some consider Bernstein's three-stage description of the freezing and freeing of degrees of freedom during motor learning too simple. To understand the criticisms, it is important to realize that a key assumption in Bernstein's framework is that the observable changes in coordination represent a reorganization in the way the movement is controlled. Freezing degrees of freedom simplifies the movement control problem presumably because it reduces the number of components that need to be controlled. As degrees of freedom are released, the underlying control mechanism should become more complex because more degrees of freedom now need to be regulated. Newell and Vaillancourt (2001) have argued, however, that the number of degrees of freedom and the complexity of the underlying control mechanism can either increase or decrease during learning depending on the many constraints that surround the task. They also note that there is often no obvious relation between the number of degrees of freedom that are regulated and the complexity of the control mechanism.[2]

### Changes in an Established or 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. Similarly, experienced tennis players use their well-learned tennis groundstrokes when first learning to hit a racquetball or badminton shuttlecock.

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 learn 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. In chapter 11, 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 for more than sixty practice trials. Participants did not consistently produce the new coordination pattern until they had performed 180 practice trials. Instability characterized the coordination patterns they produced on trials between these two demonstrations of stable patterns.

The experiment by Lee and colleagues 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 considerable practice (the actual amount varies among people). Finally, as illustrated in figure 11.4, 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. Sometimes it is necessary to go backward before one can go forward. 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.

Practitioners should also be aware that modifying coordination patterns can influence the stability of neighboring coordination patterns. Zanone and Kelso (1992, 1997) have shown that the nature of

[2]For more detailed discussions about the relationship between coordination changes and motor control during complex motor skill acquisition, see Teulier, Nourrit, and Delignières (2006), Teulier and Delignières (2007), and Zago et al. (2017).

the learner's initial coordination tendencies, which they labeled *intrinsic dynamics*, will determine which patterns become more stable or less stable when new patterns of coordination are acquired. We introduced the concept of intrinsic dynamics in chapter 11 and will examine it further in the next chapter on transfer of learning.

**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 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), dart throwing (Jaegers et al., 1989), the smash stroke in badminton (Sakuari & Ohtsuki, 2000), rowing (Lay, Sparrow, Hughes, & O'Dwyer, 2002), and the lunge in fencing (Williams & Walmsley, 2000). 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). These changes were recently reviewed and analyzed by Brueckner, Kiss, and Muehlbauer (2018).

The change in muscle use that occurs while a person learns a skill reflects the *reorganization of the motor control system* that we referred to earlier. 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 Cost**

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 learner would become a more economical (i.e., efficient) user of energy. This change, then, would be consistent with a proposal in Gentile's stages of learning model that the development of an economy of effort is an important goal of the later stages. Economy of movement refers to minimizing the energy cost of performing a skill. Beginners expend a large amount of energy (i.e., have a high energy cost), whereas skilled performers perform more efficiently, with minimum expenditure of energy.[3]

Several energy sources have been associated with performing skills. One is the *physiological energy* (also referred to as *metabolic 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 expend *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.

Researchers have been accumulating evidence only recently to support the prediction that energy

[3]Note that many prefer the term *economy* to *efficiency;* see Sparrow and Newell (1994).

## A CLOSER LOOK

### Muscle Activation Changes during Dart-Throwing Practice

An experiment by Jaegers et al. (1989) provides an easy to follow illustration of 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 of practice:* The three muscles erratically initiated activation both before and after the dart release.
- *At the end of the last day of practice:* The three muscles initiated activation according to a specific sequence.
  —The clavicular pectoralis and anterior deltoid became active approximately 40 to 80 msec prior to dart release; they turned off at dart release.
  —The latissimus dorsi became active just before dart release and remained active for 40 msec after dart release. Then, the anterior deltoid again initiated activation.

The primary muscle involved in producing the forearm-extension–based throwing action was the lateral triceps.

- *During the initial practice trials:* The lateral triceps initiated activation erratically, both before and after dart release.
- *At the end of the last day of practice:* The lateral triceps consistently initiated activation approximately 60 msec prior to dart release and remained active until just after dart release.

cost 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 practice sessions over a period of several days (Almasbakk, Whiting, & Helgerud, 2001; Durand et al., 1994). Similar decreases in oxygen use were reported by Lay, Sparrow, Hughes, and O'Dwyer (2002) for people learning to row on a rowing ergometer, which is commonly used by crew team members as a training device. Sparrow (Sparrow & Irizarry-Lopez, 1987; Sparrow & Newell, 1994) demonstrated that oxygen use, heart rate, and *caloric costs* decrease with practice 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. (For a more in-depth discussion of energy expenditure as it relates to the learning of motor skills, see Sparrow, Lay, & O'Dwyer, 2007.)

Students learning to scuba dive provide an interesting example of the decrease in physiological energy cost as measured by oxygen use. People first learning to dive typically use much more oxygen than they do when they become more experienced. The easy demonstration of this change is a comparison of the levels of oxygen used in the tanks of beginning and experienced divers. The beginners typically use more oxygen for the same length of dive.

In addition to demonstrating a reduction in energy cost, learners also experience a decrease in their rate of perceived exertion (RPE). RPE, which is a measurable subjective perception, refers to the amount of effort (i.e., exertion, or energy) a person feels that he or she is expending while performing a skill. A nice demonstration of changes in both energy use economy and RPE was reported in an experiment by Sparrow, Hughes, Russell, and Le Rossingnol (1999). Novice rowers performed on a rowing ergometer for one practice session each day for six days. The results showed that when the rowers performed at their preferred stroke rates, metabolic energy expenditure economy increased, while heart rate, oxygen consumption, and RPE significantly decreased during the six days of practice.

**Changes in Visual Selective Attention**

Because vision plays a key role in the learning and control of skills, it is important to note how our use of vision changes as a function of practicing a skill. Because we discussed most of these characteristics and changes at length in chapters 6, 7, and 9, we will mention them only briefly here. Beginners typically look at too many things, which often leads them 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.

A good example of research evidence that demonstrates the change in visual selective attention across the stages of learning is an experiment by Savelsbergh, Williams, van der Kamp, and Ward (2002). They recorded the eye movement characteristics of novice and expert soccer goalkeepers in a simulated penalty kick situation. The goalkeepers observed life-size video clips of professional players taking penalty kicks that were directed to six areas of the goal. The goalkeepers moved a joystick to intercept the ball; if they positioned it in the correct location at the moment the ball crossed the goal line, a save was recorded. As expected, the expert goalkeepers performed better than the novices, especially in terms of making more saves and better predictions of ball height and direction. In addition, the experts initiated their joystick response closer to the time of foot-ball contact, and made fewer joystick position corrections. The visual search characteristics were identified in terms of time periods before and after foot-ball contact by the kicker. Overall, the experts made fewer eye movement fixations of longer duration to fewer areas of the scene involving the kicker. These results indicated that the experts reduced the amount of visual information they needed to attend to, and they extracted more information from the most relevant parts of the scene. (Notably, a recent review of gaze behavior during anticipation in sport by Loffing and Cañal-Bruland, 2017, revealed that experts in a range of different sports tend to make fewer fixations of longer duration than non-experts, though considerable variability exists within and between individuals and across tasks.) As the kicker began the approach to the ball and eventually made ball contact, the experts progressively moved their fixations from the kicker's head to the nonkicking foot, the kicking foot, and the ball. They made very few fixations on other areas of the kicker's body. In contrast, the novices spent more time fixating on the kicker's trunk, arms, and hip areas and less time on the head, nonkicking foot, and ball. Interestingly, at foot-ball contact, the expert goalkeepers fixated on the ball more than two times longer than the novices.

**Changes in Conscious Attention Demands 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. 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


Soccer goalkeepers will develop more effective and efficient visual search strategies as their stage of learning progresses and they become more skillful.

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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. Evidence that this type of attention-demand change occurs with experience was provided by Shinar, Meir, and Ben-Shoham (1998) in a study that compared experienced and novice licensed car drivers in Israel. Results showed that while shifting gears, the novice drivers tended to miss traffic signs that the experienced drivers did not miss.

An experiment that compared novice and skilled baseball batters also demonstrates the change in conscious attention demands that occurs across the learning stages continuum. Gray (2004) had "skilled" university and "novice" recreational baseball players hit simulated baseball pitches that varied in speed and height. On some trials the players only swung at the pitches. On other trials, they had to perform a secondary task in response to an audible tone. One type of secondary task, which was extraneous to the hitting skill, required the players to verbally identify the tone as high or low. The other type of secondary task, which was related to the hitting skill, required the players to verbally identify whether the bat was moving up or down at the time of the tone. The tone occurred at any time after the ball appeared to the batter. The results showed that the extraneous secondary task led to an increase in swing errors for novice players but not for skilled players. But, when asked about the movement of the bat, just the opposite occurred as swing errors increased for skilled but not for novice players. Thus skilled players had reduced the conscious attention demanded by swinging the bat and could respond to the tone without disrupting their swing. In contrast, their swing was disrupted when they had to attend to how their bat was moving, something they did not normally do. On the other hand, the novice players were not disrupted

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### 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 along 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.

when asked about the movement of their bat because the secondary task required them to respond to something they typically gave attention to when swinging at a pitch. Interestingly, individuals with a higher propensity to consciously control their movements when learning a new skill have also been shown to have a higher propensity to freeze degrees of freedom (van Ginneken et al., 2018).

Finally, consider some experiences that you or your friends have had with learning motor skills. If you learned to type on a computer keyboard, on your first attempts to type a word or sentence you undoubtedly directed your conscious attention to each finger hitting the correct key for every letter. You probably could not carry on a conversation with a friend while you were typing because the typing task demanded all your attention. But, as you practiced and became more skilled, you no longer needed to direct your attention to your fingers and the keys for each letter, and you could talk with a friend while you typed. Similarly, when athletic trainers first learn to tape an ankle, they direct their conscious attention to the application of each strip of tape to make sure it is located properly and applied smoothly. But after a lot of practice taping ankles, trainers no longer need to direct all their attention to these aspects of taping. You can probably think of additional situations that resemble these. The examples demonstrate that a common characteristic of learning a motor skill is that the amount of conscious attention demanded by the movements of the skill itself decreases as the learner progresses along the stages of a learning continuum and becomes more skillful.

### 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.

An excellent example of research evidence that demonstrates the change in error detection and correction capability is a study involving gymnasts at different stages of learning (Robertson, Collins, Elliott, & Starkes, 1994). Novice and skilled gymnasts walked across a balance beam as quickly as possible with either full or no vision of the beam as they walked. Results showed that with no vision, both groups made significantly more form errors (unintentional deviations from a relaxed upright standing position) than with vision, but the novices made many more than the skilled gymnasts (see figure 12.3). In addition, with no vision available, the skilled gymnasts maintained the amount of time they took to traverse the beam with full vision, while the novices took almost two times longer. The skilled gymnasts maintained their movement time in the no-vision condition by taking more steps and making more form errors. The authors concluded that the results indicate that "part of becoming skilled involves developing the ability to rapidly and efficiently correct movement errors" (p. 338). It is important to add to this comment that these corrections indicate the capability to detect the errors. And, as we discussed in chapter 6, vision is an essential source for detecting and correcting these movement errors while traversing the beam.

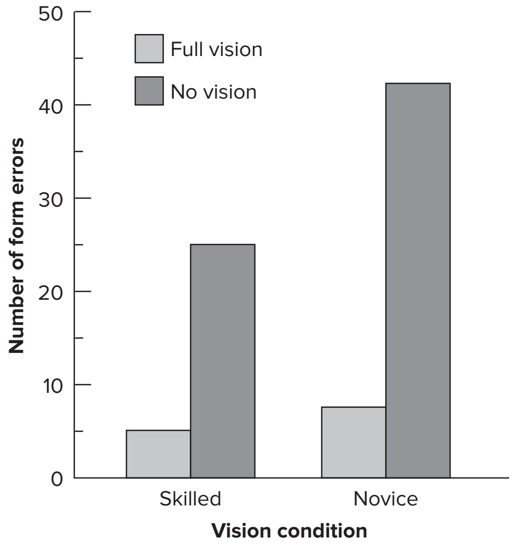


**FIGURE 12.3** The results of the experiment by Robertson et al. showing the number of form errors made by novice and skilled gymnasts as they walked across a balance beam with full vision or no vision as they walked. *Source:* Modified Figure 4, p. 337 in Robertson, S., Collins, J., Elliott, D., & Starkes, J. (1994). The influence of skill and intermittent vision on dynamic balance. *Journal of Motor Behavior, 26,* 333–339.

### Changes in Brain Activity: Plasticity

You read in chapter 4 that the behavior that occurs when we perform a motor skill has an underlying neural structure. This structure, which typically comprises several brain areas that are active at the same time, changes as beginners become more skilled at performing a skill. This activity change exemplifies the **plasticity** of the brain, which is one of its most important characteristics. (For an in-depth discussion of the history and evolution of the use of the term *plasticity* as it relates to the nervous system, see Berlucchi & Buchtel, 2009.)

With the advent of brain imaging technology, an impressive number of researchers have been actively investigating the changes in brain activity associated with the learning of motor skills. A common finding is that the brain areas active during the early stage of learning are not always the same areas active during later stages of learning (see Lohse, Wadden, Boyd, & Hodges, 2014 for a meta-analysis of research on this topic). Because of the physical limitations of the scanning devices used for fMRI and PET, the typical motor skill studied in this type of research is sequence learning. The task typically requires participants to learn to associate stimuli on a computer monitor with finger, hand, or foot movements and then practice a specified sequence of these movements.

Doyon and Ungerleider (2002; see also Doyon, Penhune, & Ungerleider, 2003) proposed a model to describe the neuroanatomy and the associated brain plasticity of motor skill learning, especially as it relates to the learning of movement sequences. They proposed that the brain structures most commonly associated with skill acquisition are the striatum (the caudate and putamen

**plasticity** changes in neuronal activity in the brain that are associated with shifts in brain region activation; these changes are commonly associated with behavioral changes or modification.

## A CLOSER LOOK

### Changes in Brain Activity as a Function of Learning a New Motor Skill

The availability of brain scanning technology has allowed researchers to investigate the brain activity associated with learning and performing a motor skill. A group of Belgian researchers used fMRI to observe the brain activity of people learning a new motor skill (Puttermans, Wenderoth, & Swinnen, 2005).

- **Participants:** Eleven right-handed adults (five women, six men; avg. age = 23.9 yrs)
- **Motor skill to be learned:** Because the study involved the use of an MRI scanner, the motor skill that participants were required to learn had to be one that could be performed while lying supine within the space limitations of the scanner. The goal of the skill was to flex and extend the right and left wrists simultaneously and continuously for 28.5 sec. The unique characteristic of the skill was that the right wrist had to move twice as fast as the left wrist during each 2 sec movement cycle. This means that the participants had to learn to flex and extend the left wrist once in 2 sec while they flexed and extended the right wrist twice in the same time period (i.e., a 1:2 frequency ratio). Each trial was 28.5 sec and included a metronome to pace the movements.
- **Practice:** Participants practiced the skill for eight consecutive days during which they performed 40 trials with visual feedback provided about the results at the end of each trial.
- **fMRI scanning:** Scanning runs occurred before training began (pretraining), in the middle of training (after day 4), and after training was completed on the eighth day (posttraining).
- **Behavioral results:** Kinematic analyses of wrist movements indicated that all participants were able to perform the skill as specified by the final day of training.
- **Brain activity results:** fMRI scans indicated the following from pre- to post training:
- ***Brain activity decreased:*** bilateral opercular areas, bilateral ventrolateral prefrontal cortex, right ventral premotor and supramarginal gyrus, anterior cingulated sulcus, and supplementary motor area.
- ***Brain activity increased:*** primary motor cortex, posterior cingulate, putamen, and right anterior cerebellum.
- **Conclusions:** In general, the brain activity changes revealed a learning-related shift from prefrontal-parietal control during initial practice to subcortical control during skilled performance.

of the basal ganglia), cerebellum, and motor cortex regions of the frontal lobe—namely the SMA (supplementary motor area), premotor cortex, and motor cortex, among others. The model indicates that these brain areas form "two distinct cortical-subcortical circuits: a cortico-basal ganglia-thalamo-cortical loop, and a cortico-cerebello-thalamo-cortical loop" (Doyon et al., 2003, p. 253). Note that the primary difference between the two loops is that one involves the basal ganglia, the other the cerebellum. Early in learning, the cortico-cerebello-thalamo-cortical loop is more involved, even though the striatum and cerebellum are typically activated together with specific motor cortex regions as the learner engages in the cognitive and motor activity that characterizes initial learning of a skill. Well-learned skills, on the other hand, involve more activity in the basal ganglia, especially the putamen and globus pallidus and the inferior parietal lobe of the cerebral cortex.

In general, then, as the movements of a motor skill become more "automatic," which would occur when a person is in the Fitts and Posner autonomous stage of learning, "a distributed neural system composed of the striatum and related motor cortical regions, but not the cerebellum, may be sufficient to express and retain the learned behavior" (Doyon et al., 2003, p. 256). The model proposes that the early involvement of the cerebellum in learning a motor skill seems to be related to adjusting movement kinematics according to sensory input in order to produce an appropriate movement. Results of several fMRI and PET studies have shown general support for the Doyon and Ungerleider model, although specific brain areas active at the various stages of learning may differ depending on the skill that was learned in the experiment (see, for example, Doyon et al., 2009; Doyon & Habib, 2005; Grafton, Hazeltine, & Ivry, 2002; Lafleur et al., 2002; and Parsons, Harrington, & Rao, 2005).

Finally, two other points are important to note regarding learning-induced changes in the brain. First, the automatization of motor skills is associated with an overall reduction in cortical activity, suggesting improvements in processing efficiency that are consistent with efficiency gains in other systems during motor skill learning (Gobel, Parrish, & Reber, 2011). Second, the brain undergoes structural changes in addition to functional changes when new skills are learned. In one of the first demonstrations of such changes, Draganski et al. (2004) showed that three months of juggling practice led to a significant, though temporary, bilateral increase in the density of gray matter in the midtemporal area and in the left posterior intraparietal sulcus. Both of these areas are associated with the processing and retention of visual information. Subsequent research has confirmed that similar changes occur when other complex motor skills are acquired and that the organization of white matter pathways also change with practice (see Zatorre, Fields, & Johansen-Berg, 2012, for an excellent review of work in this area and Steele & Zatorre, 2018, for a discussion of current directions in this line of research).

Another method used to examine structural and/or functional changes in the brain associated with motor learning is to examine the brains of elite athletes in a resting state or when engaged in motor imagery or rehearsal of performance. This method is consistent with studies described at the end of the chapter that focus on how experts differ from non-experts on a range of perceptual, cognitive, and motor measures. Neuroplastic differences in brain structure and/or function have been observed in archers (Chang et al., 2011; Kim et al., 2008, 2014), badminton players (Di et al., 2012), basketball players (Park et al., 2009, 2015), dancers (Calvo-Merino et al., 2005; Giacosa et al., 2016; Hänggi et al., 2010), golfers (Jäncke et al., 2009), gymnasts (Huang et al., 2018), racing-car drivers (Bernardi et al., 2013), and rock climbers (Paola et al., 2013). Consistent with the idea that long-term training induces changes in neural processing efficiency, the world-class gymnasts studied by Huang et al. (2018) showed significantly lower resting state intra-network functional connectivity in the basal ganglia, the anterior default mode network, and the left and right fronto-parietal networks, though functional connectivity was higher in the extrastriate visual network, compared to non-athlete controls. In addition, the gymnasts showed lower inter-network functional connectivity between the sensorimotor network and the basal ganglia, cerebellum, and primary visual networks, between the basal ganglia network and the primary visual network, and between the posterior default mode network and the right fronto-parietal network than controls. Again, these findings do not imply the brain regions studied were not as connected as they were in controls; the regions were simply less active in the resting state as a result of greater efficiency in the gymnasts' brains.

## A PERFORMER CHARACTERISTIC THAT DOES NOT CHANGE ACROSS THE STAGES OF LEARNING

Researchers who have investigated the use of sensory feedback across the stages of learning have consistently shown that *learning is specific to the sources of sensory feedback available during practice.* This means that if we use visual feedback during practice in the first stage of learning, we continue to need to use it in the same way as we become more skillful in later stages. Proteau and Marteniuk (1993) presented a good example of research evidence of this feedback dependency. They allowed participants to see their movements as they learned to perform a 90 cm aiming movement in 550 msec. Then, after 200 or 2,000 practice trials, the visual feedback was removed. We would expect that if the participants had learned to rely on sensory feedback sources other than vision as they practiced, increasing the amount of practice with vision would decrease the need for vision to perform the skill. However, the results showed just the opposite effects. Participants who had visual feedback removed after 2,000 trials performed less accurately than those who had

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**Practice Specificity: Mirrors in Dance Studios and Weight Training Rooms**

If you walk into most dance studios and weight training rooms, you will see full-length mirrors on at least one wall, if not more. The most common reason given for their presence is that they provide an added source of visual feedback that will help the dancers and lifters improve their technique. But according to the evidence discussed in this chapter about practicing with this type of visual feedback when the performance context does not include mirrors, the mirrors may hinder learning more than they help it.

According to several studies by Luc Proteau and others, the longer people practice in the presence of this type of visual feedback, the more dependent on that feedback they become. This means that when an individual must perform without the mirror, that person will not perform as well as if he or she had practiced without the mirror all along or, at least, for enough time to not depend on the mirror.

***Powerlifters:*** Tremblay and Proteau (1998) provided evidence that this view applies to powerlifters learning to "perfect" their form for the squat lift. When the lifters who practiced with a mirror for 100 trials were asked to perform the lift without the mirror, they increased the amount of error of their knee joint angle by 50 percent. Rather than the mirror helping them perfect their form, it led to poorer form when the mirror wasn't available.

***Dancers:*** Although we don't have research evidence based on dancers, we have evidence that some professional dance teachers do not use mirrors during classes and rehearsals. Two examples were described in the magazine *The New Yorker* (January 6, 2003) in an article by Joan Acocella. After the author observed a dance class taught by the great ballerina Suzanne Farrell, she stated, "Again and again, she tells dancers to stop looking in the studio mirror" (p. 53). The other example involves George Balanchine, the originator of the New York City Ballet Company, considered by many to have been one of the world's best choreographers. Balanchine forbade his dancers to look in the mirror. He told them, "I'm the mirror" (p. 53).

it removed after 200 trials. Rather than decreasing their dependency on visual feedback, the participants increased dependency. Similar results were reported for participants learning the same type of manual aiming task with visual feedback but then having it removed after 100, 1,300, and 2,100 trials (Khan, Franks, & Goodman, 1998). Other types of motor skills have also shown this effect, such as walking across a balance beam (which you saw in the preceding section), walking a specific distance on a narrow line on the floor (Proteau, Tremblay, & DeJaeger, 1998), a serial arm movement skill (Ivens & Marteniuk, 1997), one-handed catching of a thrown ball (Whiting, Savelsbergh, & Pijpers, 1995), and a weightlifting skill (Tremblay & Proteau, 1998).

Why does dependency increase for sensory feedback sources available during practice as a person advances through the stages of learning? Proteau and his colleagues hypothesize that the dependency develops because the sensory feedback becomes part of an integrated sensory component of the memory representation of the skill. As a result, if the person must perform without the same sensory feedback available, retrieval of the representation from memory is less than optimal, because the sensory information available in the performance context is not compatible with the sensory information stored in the memory representation of the skill. Consequently, performance is less accurate than it would have been with all the stored sensory information available in the performance context.

## 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

### A CLOSER LOOK

**Steve Blass Disease**

Steve Blass was a professional baseball player who pitched for the Pittsburgh Pirates. Over a ten-year career he had over 100 wins, made the National League All-Star team, and finished second in the voting for the 1971 World Series MVP, behind his teammate Roberto Clemente. Despite his stellar career, Steve Blass is best remembered for his sudden and bizarre loss of control over his pitches during the 1973 season. He walked a significant number of batters, struck out very few, and had an ERA that shot up to 9.81. He spent the majority of the 1974 season in the minor leagues and then retired in 1975. Steve Blass disease is now commonly used in baseball circles to refer to a highly skilled pitcher who abruptly and inexplicably loses the ability to control his throws.

Coaches, commentators, and researchers have proposed various explanations for Steve Blass's precipitous loss of skill in pitching the baseball; however, most center on the detrimental effects associated with focusing on the throwing mechanics during the pitch. In chapter 9, you learned that focusing on movements rather than movement effects has a detrimental effect on performance and often leads to choking. Whether or not this explanation is correct is open to speculation. Blass, himself, said that he tried a multitude of remedies to deal with his malady, but to no avail—absolutely nothing worked. Given the number of high-profile performers and athletes who have suffered similar precipitous and unexplained losses in skill, this area is ripe for additional research. The topic of loss of skill is rarely considered in the skill acquisition literature.

To hear an interesting interview with Steve Blass about Steve Blass disease, go to http://www.thisamericanlife.org/radio-archives/episode/462/own-worst-enemy?act=1. For more about Steve Blass's career, you can read his autobiography *A Pirate for Life*.

the 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 skill 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 the first 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.* The critical point in this statement is "intense practice." Although the length of time is relevant, more important for the attainment of expertise is the type of practice in which a person engages. According to Ericsson and his colleagues, the specific type of intense practice a person needs to achieve expertise in any field is *deliberate practice,* which refers to "individualized training activities especially designed by a coach or teacher to improve specific aspects of an individual's performance through repetition and successive refinement" (Ericsson & Lehmann, 1996, p. 278f). During this type of practice, the person receives optimal instruction, as well as engaging 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. Research investigating the deliberate practice hypothesis has consistently found support for the influence of this type of practice on the development of expertise in many different performance domains, such as sports, ballet, music, painting, surgery, etc. (see

Anderson & Mayo, 2015; Baker & Young, 2014; Ericsson, 2008; Ericsson & Williams, 2007, for reviews of this research although a different perspective is presented in a review of the deliberate practice effect by Macnamara, Hambrick, and Oswald, 2014).

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. (For evidence supporting the sport-specific nature of expertise, see a study of elite triathletes and swimmers by Hodges, Kerr, Starkes, Weir, & Nananidou, 2004.)

**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 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.

***Problem solving, decision making, and anticipation.*** 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; anticipate what the defenders and his or her teammates will do; then 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 7 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. (For evidence involving skilled soccer players, see Van Maarseveen, Oudejans, & Savelsbergh, 2015, and for a range of other sports see Loffing & Cañal-Bruland, 2017.) 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.[4]

**Expertise and Automaticity**

Based on the earlier discussion about stages of learning, one might assume that experts are almost guaranteed to reach a stage of effortless automaticity in their performance. According to Ericsson (1998), nothing could be further from the truth—the common belief that expert performance is fully automated is completely false. Ericsson argues

[4]See Abernethy (1999) for one of the seminal discussions of the differences between experts and novices in the use of vision.

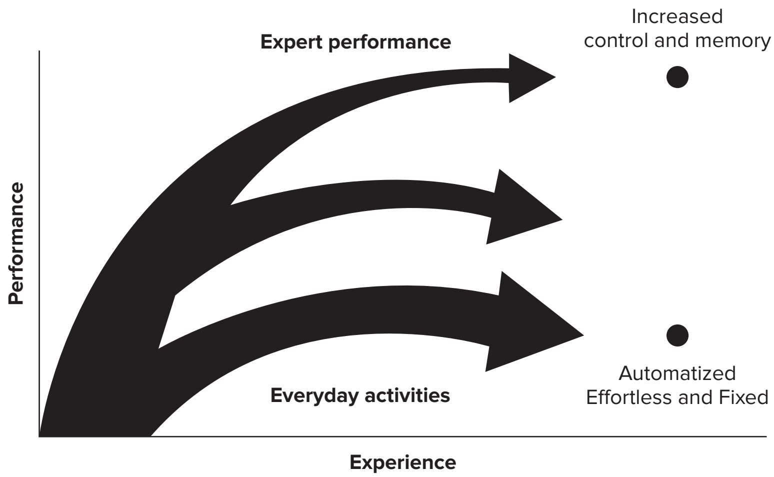


**FIGURE 12.4** An illustration of the qualitative difference between the course of improvement of expert performance and everyday activities. The goal for everyday activities is to reach a satisfactory level that is fixed and automated and then executed with a minimal amount of effort. In contrast, expert performers counteract automaticity by developing increasingly complex mental representations to attain higher levels of control of their performance. *Source:* From Ericsson, K. A. (1998). The scientific study of expert levels of performance: General implications for optimal learning and creativity. *High Ability Studies, 9,* 75–100.

that during the learning of everyday skills, people reach an acceptable level of performance and are then happy to devote minimal attention to the skill, consequently losing conscious control over modifying it. The skill often stagnates in this scenario even though the learner continues to practice it. In contrast, the expert attempts to avoid the stagnation associated with complete automaticity because of the desire and need to make continued improvements and to cope with new situations (see figure 12.4). Think aloud protocols, in which experts verbalize their thoughts as they make decisions, reveal that expertise in a wide range of domains is mediated by increasingly complex cognitive control processes. In addition, superior performance is associated with higher levels of recall of specific pieces of information, consistent with a high degree of conscious awareness during performance. In essence, the expert seems to recycle through the earlier stages of learning, though in a much more sophisticated way than the beginner, in an attempt to take advantage of higher cognitive processes. If Ericsson is correct, then conscious controlled processing, originally thought to be confined to the beginning stages of learning a new skill, could make a major contribution to the expert's capacity to adapt performance to a wide range of different situations.

## SUMMARY

- When people begin to practice a new motor skill, and continue to practice the skill, they typically progress through distinct, although continuous, stages of learning. We discussed two models that describe these stages.
- The *Fitts and Posner model* proposes that the learner progresses through three stages:
  - ► *Cognitive stage*—The beginner engages in much cognitive activity such as problem solving, directing attention to the movements, and so on.
  - ► *Associative stage*—In this intermediate stage the learner reduces the amount of cognitive activity involved in performing the skill and works to refine the skill to increase performance success and consistency.
  - ► *Autonomous stage*—The learner performs skillfully, almost automatically, with little conscious attention directed to the movements.
- *Gentile's model* proposes that the learner progresses through two stages:
  - ► *Initial stage*—The goals of the beginner are to develop a movement coordination pattern that

will allow some degree of successful performance and to learn to discriminate regulatory and nonregulatory conditions.

- ► *Later stages*—The learner's goals are to acquire the capability of adapting the movement pattern acquired in the initial stage to specific demands of any performance situation; to increase performance success consistency; and to perform the skill with an economy of effort. Movement goals are skill specific in this stage, as closed skills require a *fixation* of the movement pattern, whereas open skills require a *diversification* of the movement pattern.

- Bernstein described learning a new skill as solving a motor problem and compared the learning process to staging a play. He proposed that the learner progresses through multiple stages when acquiring a new skill and described effective practice as a form of *repetition without repetition*.

- Several distinct performer and performance changes occur as the learner progresses through the learning stages. We discussed the following changes:
  - ► *Rate of improvement:* The amount of improvement decreases (*power law of practice*).
  - ► *Movement coordination:* To control the many degrees of freedom required by a skill, the beginner initially "freezes" certain joints but eventually allows the limb segments involved to work together as a functional synergy.
  - ► *Complexity of control:* The complexity of the underlying control mechanism may increase or decrease depending on task demands.
  - ► *Altering an established or preferred coordination pattern:* Learners typically use preferred patterns of coordination initially, but these patterns lose stability with practice and are replaced by stable and more functional coordination patterns.
  - ► *Muscles involved:* The number of muscles activated by a beginner decreases with practice; the timing pattern of muscle activation becomes optimal for successful performance.
  - ► *Energy cost/movement efficiency:* The amount of energy beginners use decreases; movement efficiency increases.
  - ► *Visual selective attention:* Visual attention increasingly becomes directed specifically to appropriate sources of information.
  - ► *Conscious attention:* The amount of conscious attention given to the movement characteristics of a skill is reduced.
  - ► *Error detection and attention:* The capability to detect and correct one's own performance errors increases.
  - ► *Brain activity:* Specific brain regions activated during the initial stage of learning are not always the same areas activated during later stages. Processing efficiency increases.

- A performer characteristic that *does not change* across the stages of learning is the reliance on sensory information that was available during the early practice stage.

- *Expertise* refers to a high level of skill performance that characterizes a person at the extreme opposite end of the learning continuum from the beginner.
  - ► Expertise is typically the result of *deliberate practice* for a minimum of ten years.
  - ► Experts have a *knowledge structure* that is organized into more concepts related to performing the activity, and they are better able to interrelate the concepts. However, the knowledge structure is activity specific.
  - ► Experts who perform in activities that involve severe time constraints for decision making and anticipation visually search the performance environment in a way that allows them to select more meaningful information in a short amount of time.
  - ► Experts may resist allowing all aspects of their performance to become automated to enable continued improvements and adaptation to new situations.

## POINTS FOR THE PRACTITIONER

- When working with people who are at the initial stage of learning, the emphasis of instruction should be on achieving the action goal. Allow beginners the opportunity to explore various movement options to determine which movement characteristics provide them the greatest likelihood of success.
- Expect beginners to make many movement errors and be inconsistent in how they perform the skill from one attempt to another.
- After beginners have demonstrated that they can perform a skill with some degree of success, the emphasis of instruction should be on refining the skill and performing it more efficiently.
- Instruction for closed and open skills should be similar for beginners, with an emphasis on their developing movement characteristics that enable them to experience some degree of success at achieving the action goal of the skill. But after they have achieved this level of success, instruction for closed and open skills should differ. For closed skills the emphasis should be on the repetition of successful movements in situations that would occur in the environmental context in which the skill would be performed; for open skills the emphasis should be on successful adaptation to a variety of regulatory conditions that would typify the open skill being learned.
- Expect beginners to show large amounts of improvement relatively quickly, but lesser amounts of improvement as more skill is developed. It may be necessary to remind learners of this characteristic to motivate them to continue to practice when they experience less improvement than previously.
- Expect beginners to perform a skill with movement strategies that resemble those they used for a skill they have previously learned and experienced. These strategies may help them initially experience success achieving the action goal of the skill but will eventually impede them from achieving levels of success that would characterize a skillful performer—that is, an expert.

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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 occur as a person progresses through the stages of learning a motor skill.
4. Describe a performer characteristic that does *not* change across the stages of learning. Describe an example.
5. Describe who 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?

**Specific Application Problem:**

(a) You are working in your chosen profession. Describe a motor skill that a person you are working with is trying to learn, relearn, or improve performance of. Specify which stage of learning this person is in.

(b) Describe the performer and performance characteristics you would expect to see for this person.

(c) Describe how the characteristics you described in part b should change as the person learns the skill.