CHAPTER 2

What Is a Skill?

ANDY CLARK/Reuters/Landov

"I was not successful as a ball player, as it was a game of skill."

Casey Stengel (1890–1975), professional baseball manager

KEY QUESTIONS

- What is a skill? How are skills defined?
- How do motor skills differ from other types of skills?
- Are there characteristics common to all motor skills?
- What factors influence the performance of motor skills?
- What problems do researchers confront when studying motor skills?
- How can motor skills be meaningfully classified?

CHAPTER OVERVIEW

If you were presented a list of motor skills including the shot-put, completing a maximal weight bench press, and casting in fly fishing, which two would you select as having the most in common? Most people would probably select the shot-put and bench press as being the most similar. And if you focus only on the muscular effort required to accomplish both of these skills, your choice would be the most logical one. But if you consider all of the essential characteristics of these three skills—the perceptual requirements for each, the patterns of muscular coordination and timing involved in each, the demands imposed on each by the environment, the basic movement goals for each—then fly fishing and the shot-put actually have much more in common with one another than either has with the skill of bench pressing.

Analyzing skills for common features is more than a mere exercise in identifying similarities, however. For one thing, such analysis forms the basis for determining the most effective methods for instructing motor skills. In our example, many of the instructional methods best suited to teaching someone to put the shot are the same as those that should be used when teaching someone to cast a fly line to the spot where the biggest trout hide out, but these same instructions would prove less effective when teaching someone the proper mechanics for performing the bench press.

In this chapter, we will consider questions concerning the nature of skills, including what all skills have in common as well as those features differentiating various types of skill. As we begin our journey of discovery in this book, we will examine the ways in which movement scientists conceptualize skills, the theoretical problems confronted in studying skilled behaviors, and the vocabulary used to communicate effectively about motor skills. This chapter forms an essential component of the foundation upon which our subsequent explorations into motor learning and control are built.

The word *skill* is easily and, for the most part, meaningfully understood by almost everyone. When we say that someone is a skilled typist, or a skilled tennis player, or an unskilled driver, everyone understands what we mean. We can also refer to particular kinds of behaviors as skills. We say that writing is a skill, as are playing the piano, using tools, solving mathematical problems, square dancing, and hitting fastballs. Again, our meaning is clear to everyone.

When we begin to study skills scientifically, however, our everyday use of the term soon leads to disagreement and uncertainty. It does so because our everyday usage of the word *skill* is too vague, lacking the necessary precision to sufficiently illuminate the similarities and differences among skills in which researchers and practitioners alike are interested. What is common to all activities defined as skills? To be a skill, must an activity be performed at some minimum level of proficiency? Are all skills learned, or can some be inherited? What do movement skills have in common, if anything, with other types of skills? What is the best way to study and learn about skills? Addressing such questions requires that our definition of skill be embedded within a theoretical framework that provides consistency and meaningfulness in usage. Defining *skill* scientifically is the first step in developing a theory about how people acquire skillful behaviors, and how practitioners can design more effective evaluation and training programs.

THE DOMAINS OF SKILL

Do we use the word *skill* to mean the same thing when we say that Mary is a skilled mathematician and John is a skilled first baseman? Certainly something about our meaning is the same; in both cases we mean to indicate that our subjects perform their respective skills at a high level of proficiency—Mary gets straight A's in math and John is on the varsity baseball team. What about Hector, a connoisseur of fine wines, who is so skilled that he can tell the vintage, year, and bottler of any wine just by tasting it. Is he skilled in the same way as are Mary and John?

Mary, John, and Hector are each skilled at their respective area of interest. But it is also clear that what each is skilled at doing is very different. Mary's skill comes from her capacity to think about abstract symbols and to manipulate them in her head. Hector's ability to discern various wines indicates a highly developed sense of taste discrimination. Of course, Hector's ability to discern various wines comes from a great deal of experience and knowledge about different vintners. So, in his use of knowledge concerning wines, his skill has some things in common with Mary's (although, if he acquires too much experience at wine sampling, he may not pass many math tests!).

John's ability, compared to Mary's and Hector's, is expressed primarily through bodily movements. He is quick off the ball, can coordinate his limbs to perform complex and exacting movements, and possesses good catching and throwing abilities. But are John's skills merely physical? To be a skilled baseball player, he must also act out of considerable knowledge concerning game situations. Often he must make split-second decisions about a situation and how best to respond—something requiring considerable knowledge on his part. John has also developed keen capabilities at watching a ball fly off of a hitter's bat, and can quickly and accurately perceive how he must move to catch it.

There are similar elements of skill in each of the examples above, as well as elements of each that are different. Mary, John, and Hector are all highly skilled, but they are skilled at different things. Mary is skilled primarily because of her cognitive abilities; Hector, because of his perceptual awareness; and John, because of his movement capabilities. In the study of skilled behavior, these specific capacities are called cognitive, perceptual, and motor skills.

Skill Domains

skill domain: A categorical classification of skills possessing similarities specific to cognitive, perceptual, and motor characteristics.

A skill is initially defined as belonging to one of three domains. A domain is simply a category into which similar things can be grouped. A **skill domain** is the grouping of skills based upon the underlying capacities most essential for accomplishing them. When defining a skill, our first decision entails deciding whether cognitive, perceptual, or motor capabilities are most necessary to the successful completion of the skill.

Cognitive Skills

cognitive skill: A skill for which success is primarily determined by an individual's knowledge and cognitive capabilities.

A **cognitive skill** is one in which knowing what to do or how to do it is the most important aspect in accomplishing the skill. Although perceptual and motor elements may make up part of a cognitive skill, understanding and knowing are the most essential capabilities for doing the skill well, and are usually the most difficult to master. We can define a cognitive skill as one in which success in accomplishing the goals of the skill is primarily determined by an individual's knowledge and cognitive abilities. Examples of cognitive skills include reading, writing, solving mathematical problems, doing crossword puzzles, memorizing a list of names, constructing a reasoned and persuasive argument, diagnosing an athlete's injury, computer programming, and calling plays in a football game.

Perceptual Skills

perceptual skill: A skill for which the ability to discern and discriminate among sensory stimuli is of primary concern in successfully accomplishing the skill.

A **perceptual skill** is one in which the ability to discern, or to discriminate among, sensory stimuli is of primary importance in accomplishing the skill successfully. More simply stated, it is the ability to recognize important things in the environment—that is, to detect information. In accomplishing a perceptual skill, the primary goal of the performer is not in possessing the movement capabilities necessary for acting, but in sensing when and how to act.

Perceptual skills are intricately intertwined with movement skills, such as those found in sports, so that it can sometimes be difficult to separate the contributions of each type of skill to successful performance. Is the sensory acuity necessary to discern where and when a pitched baseball will cross home plate more or less important than the actual movement patterns required for hitting the ball, for example? So essential are perceptual abilities in accomplishing most motor skills, in fact, that motor skills are often referred to as *perceptual-motor* *skills*. Still, many skills rely primarily upon an individual's awareness of sensory stimuli and are therefore grouped under the perceptual domain.

A perceptual skill can be defined as one in which successfully accomplishing the goal of a skill is primarily determined by an individual's ability to recognize and discriminate among various sources of perceivable stimuli. Examples of perceptual skills include selecting good melons at the grocery store, adjusting the color on a television set, sorting eggs by size, "reading" a defense in football, identifying the ingredients in food by taste, maintaining balance when walking on an icy path, and spotting a camouflaged enemy in a woody thicket.

Motor Skills

As we have seen, motor skills are not performed in isolation from perceptual and cognitive components necessary for task completion. In many of the skills of interest to the movement specialist, however, it is the quality of the movement itself that is of paramount importance. A motor skill is one in which the primary determinant of success is the quality of movement. For example, a bowler may have no trouble knowing what to do (knock down the pins with the ball) or in perceiving how to do it (the length and width of the bowling lane, the location of pins, and the weight of the bowling ball are constant and easily discernable from trial to trial), but producing the correct movements to accomplish the goal of knocking all 10 pins over with one ball is still a challenge in each frame. Where cognitive skills emphasize knowing what to do, and perceptual skills getting the information to do it, motor skills are concerned with doing it, and doing it correctly.

There is a tendency to think of motor skills only in terms of sports skills or other specialized activities. Catching a football, serving a tennis ball, performing a somersault, skate boarding, and square dancing are certainly all motor skills. But we perform motor skills in most of our daily activities—thousands of them forming the essential and routine, meaningful and pedestrian, events that make daily life possible. Motor skills include washing dishes, brushing your teeth, turning on a lamp, shaking someone's hand, putting on your clothes in the morning, taking a shower, sitting down and standing up, driving to school, dancing for joy when you get an "A" in organic chemistry, and climbing into bed at night (or for a well-deserved nap after your organic chemistry test). Many occupations consist of learning to perform specialized motor skills—using machinery, repairing computers or car engines, sorting and stacking items on shelves, playing the piano professionally, wrapping an injured athlete's ankle, performing surgery, or flying the space shuttle. Even skills that we might first be inclined to consider purely cognitive, like talking and writing, have significant motor elements underlying their successful production (you can think about what you want to say, but speaking requires the sophisticated and finely tuned coordination of muscles within the vocal tract in order to produce words).

As these activities classified as motor skills indicate, many different types of activity rely primarily upon movement for their success. We should again emphasize that motor skills, as with cognitive and perceptual skills, are so labeled because of the degree to which cognitive, perceptual, or motor elements contribute to the successful accomplishment of task goals. Few real-world skills do not contain elements of all three domains; it is convenient both theoretically

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Many skills include significant components of all three skill domains: cognitive, perceptual, and motor.

and practically, however, to label skills relative to the major domain responsible for successful goal achievement. Any skill, and perhaps especially a motor skill, is a mosaic of cognitive, perceptual, and motor strands woven and blended together into the rich tapestry of skilled human behavior (see Figure 2.1).

Is Skill Learning Domain Specific?

Given both the differences and similarities of the three domains into which skills can be classified, it is reasonable to ask if cognitive, perceptual, and motor skills are acquired in fundamentally different ways. That is, are there three separate and distinct sets of skill-learning principles, a different set for each domain? At first it might seem that differences in the primary modality of success in each domain of skill would naturally lead to differences in methods of acquiring each, and in turn differences in the best ways of instructing each. As we have seen, however, skills are always, at least to some degree, composites of all three domains, so that questions of differences in how each type of skill is acquired are not as clear-cut and easily differentiated as they might on initial reflection seem.

Although there remains some debate on this issue, there is a growing body of evidence that cognitive, perceptual, and motor skills are acquired in essentially the same way (Allman, 1999; Gardner, 1983; Heathcote, Brown, and Mewhort, 2000; Rosenbaum, Carlson, and Gilmore, 2001). Similarities among skills in all three domains include the following:

1. **Transfer specificity—**Practicing a particular skill generally has little if any influence on other skills (Kramer, Strayer, and Buckley, 1990; Singley and Anderson, 1989)
2. **Learning rates—**Charting the rate of learning in all three domains results in similar patterns which can all be described by the same mathematical power function rules (i.e., learning in all three domains follows the same mathematical regularities) (Neves and Anderson, 1981; Singley and Anderson, 1989)
3. **Learning stages—**Learners appear to progress through the same stages of learning regardless of the skill domain (Anderson, 1982; Fitts and Posner, 1967)

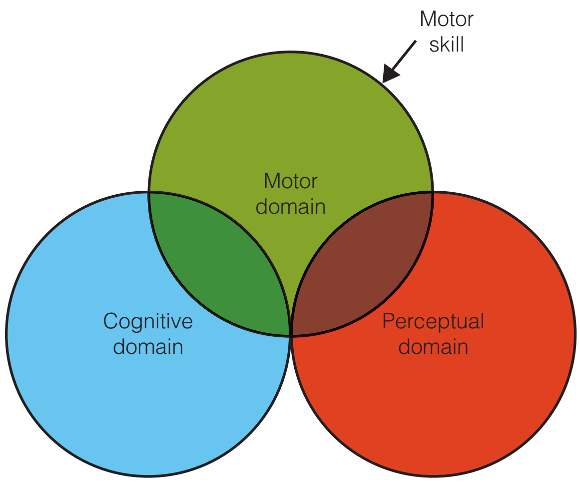

FIGURE **2.1** Motor Skills Include Aspects of the Cognitive and Perceptual Domains of Skill

Source: Created by author.

BOX 2.1 Into Which Skill Domain Should Driving Be Classified?

All skills are composed of aspects from each of the three skill domains. The contributions of each domain may be so significant, in fact, that it can sometimes be difficult to decide into which domain a particular skill should be classified. How should driving an automobile be classified, for example? Certainly there are essential cognitive demands when driving. A driver must know the rules of the road, as well as understand operating procedures such as shifting gears and steering around corners. Perception is also essential to driving. Detecting changes in road conditions, other traffic, and one's own car speed and direction require constant monitoring of an ever-changing array of sensory information. Finally, a driver must coordinate both the knowledge of driving and the perception of the driving environment with correct motor responses involved in steering, accelerating, braking, and shifting gears in order to accomplish driving skills efficiently and safely. Given the essential contributions of each skill domain when a person is operating an automobile, would you classify driving as a cognitive, perceptual, or motor skill?

4. **Individual differences in skill performance—**The general correlation between how well individuals perform any two dissimilar skills is highly consistent across all three skill domains (Gardner, 1983)
5. **Importance of imagery—**Once thought to play a role only in cognitive learning, recent research has revealed the important role imagery plays in the learning of perceptual and motor skills, as well (Billard, 2001; Crammond, 1997; Jeannerod, 1994)
6. **Involvement of neural substrates—**Recent research has revealed that there is significantly less differentiation than once thought between areas of the brain involved in generating the three types of skills, especially a more important role of the cerebellum in cognitive as well as perceptual and motor skills than was previously believed (Courchesne and Allen, 1997; Fiez, 1996)
7. **Similar training effects—**Many similarities exist in the effects of various training regimens on the learning of skills in all three domains, including practice distribution effects, effectiveness of varied practice scheduling, and the roles of instruction and feedback (Schmidt and Bjork, 1992).

The final point just made, that similarities exist in the training effects of various practice arrangements and methods among all three skill domains, should be especially noted. We will see throughout our study that problems arise, and relatively ineffective instructional methods frequently follow, when we forget that all three skill domains share more commonalities than differences. Indeed, advances in neuroscience have led experts from across the spectrum of skill domains to conclude that common neural mechanisms underlie the acquisition of all skills, and even that all skills are performatory in nature. In this view, all skills are related to an action system. Cognition and perception exist fundamentally to subserve action, and are intrinsically linked to the motor system and to the acquisition of motor skills (Smyth and Haggard, 1999; Rosenbaum, Carlson, and Gilmore, 2001).

BUT WHAT, EXACTLY, IS A SKILL?

Having distinguished among the three domains into which skills are grouped, the reader might still be left with the question, What, exactly, is a skill? Or, to be more precise, What is a motor skill?

BOX 2.2 Is There a Correlation between Intelligence and Motor Skills?

There is growing evidence that intelligence and proficiency at motor skills, especially motor coordination, are significantly correlated. Large studies of school-age children in both Europe and the United States have reported links between measures of intelligence and levels of motor coordination. In one study, children with higher cognitive status were found more capable of carrying out complex motor tasks than were children of lower cognitive status. Findings like these support the growing conclusion among scientists in several fields of study that a common neurological mechanism or factor supports cognitive, perceptual, and motor activities. Although debate still exists over what this factor might be, scientists studying human intelligence have begun to include motor intelligence as an important field of study.

Defining Skills Generally

Jack Adams, one of the founding fathers of modern motor learning research, in an important review of the history of motor skill research concluded that the term "skill is not favored with a clear outline" and that "analysts have been struggling with its definition for decades" (Adams, 1987, p. 41). Although there are points of contention among researchers and motor learning theorists relative to what should be emphasized given different theoretical perspectives, a workable definition of skill (and motor skill) useful to the student interested in the domain of motor skill learning can still be offered.

Our discussion thus far has resulted in the classification of a diverse array of activities as skills. This leads to the first of three important elements in defining skill: (1) Skills entail a broad range of human behaviors. As we have seen, those behaviors classified as skill range from activities emphasizing cognitive elements to those in which perceptual and motor elements dominate, as well as varying combinations of all three. Thus, the many types of activity classified as skills are broad and diverse, making up a large part of people's daily activities.

Though skills represent a wide range of human behavior, they all have one important feature in common. This leads to the second element in defining skill: (2) Skills are goal-oriented; they are directed toward the attainment of a specific goal. Skills are purpose driven and, therefore, voluntary. A performer purposefully initiates action to achieve a specific goal.

Finally, (3) skills are learned. Individuals acquire an improved capacity to achieve desired goals through experience or, frequently, intentional practice. It is in this sense that we can say that a person is unskilled or highly skilled at an activity, depending on his or her degree of learning rather than on some underlying capacity or ability that is genetically acquired. Some skills, like walking, are learned through developmental processes involving interaction with the environment. Others, like turning a light switch on and off, are learned through often repeated (but not intentionally practiced) experiences. Yet other skills, including most everyday and virtually all specialized skills, are learned through intentional practice.

skill: A learned, goal-directed activity entailing a broad range of human behaviors.

We can offer the following working definition of a **skill**:

> A skill is a learned, goal-directed activity entailing a wide range of human behaviors.

Defining Motor Skills Specifically

Our proceeding discussion resulted in a general definition of skill, regardless of the specific domain of skill addressed. What about motor skills specifically, though? Defining motor skills entails the same three components used with the more general definition of skill but also addresses the contributions of the motor system and movement in accomplishing skill goals. Narrowing our definition of skill to motor skills, we can say that (1) motor skills cover a broad range of behaviors accomplished primarily through the coordination of limbs and body segments brought about through involvement of the musculature. (2) Motor skills are directed toward the accomplishment of specific environmental goals, and goal attainment is importantly dependent on movement. Although any skilled behavior involves combinations of cognitive, perceptual, and motor processes in varying degrees of importance, motor skills refer to performance that is "muscular," that is, where muscular activity is the primary determinant in goal attainment. (3) Motor skills are learned. Motor skills do not result from the activity of reflexes or inherent natural abilities—they must be learned. Motor skills range from simple actions easily learned, such as depressing a telegraph key on signal, to complex sports skills requiring lengthy periods of practice to master.

Folding these features into definitional form, we can offer the following expanded definition of a **motor skill:**

motor skill: A learned, goal-directed activity accomplished primarily through muscular contributions to action.

> A motor skill is a learned, goal-directed activity accomplished primarily through muscular contributions to action and entailing a broad range of human behaviors.

This definition, referred to as the classic definition of motor skill, represents a categorical definition. This means that any activity or behavior so described is, by definition, a motor skill. That is, it is a definition that circumscribes all behaviors considered motor skills, regardless of the quality of those behaviors. In this sense, it is a definition of motor skill as a "thing." This is a widely accepted definition pervasive in the literature and echoed by many authors over the years, so that we might label it as the classic definition of motor skills.

Defining Motor Skills by the Characteristics of Skilled Performance

The classic definition of motor skills just presented highlights an important characteristic of skills—they can be improved! This has led many skill analysts to include in their definition of motor skill those features distinguishing relatively poor, or unskilled, performers from highly skilled performers. That is, the extent and quality of learning becomes an important aspect of how motor skill is defined.

A definition of motor skill in terms of the characteristics separating performers of various skill levels was offered in 1952 by Guthrie and has continued to influence the definition of motor skills to the present. Guthrie posited that all motor skills consist of the ability to bring about some end result with maximum certainty and a minimum outlay of energy, or of energy and time.

There is intuitive appeal in Guthrie's definition. In particular, it highlights the qualitative aspect of motor skills. That is, different individuals performing the *same* skill can exhibit varying quality of performance. Specific in Guthrie's definition are three features separating unskilled from skilled performers. (A comparison of Guthrie's definition of skill with that of the classic definition is shown in Table 2.1.)

1. **Maximum certainty of goal achievement.** An important quality of skill proficiency is the ability to achieve the task goal with a maximum of certainty. In laboratory research concerned with motor skill learning, certainty is measured by the reduction (change) in error measures over acquisition. In sports settings, certainty is the primary determinant of skill. A kicker in football who misses all of his team's attempted field goals, even if his kicking form is perfect, would not be considered skilled.

2. **Minimum energy expenditure.** For many motor skills, proficiency is achieved through the minimization of energy required for performance. The conservation of energy is essential to high-level performance in energy-demanding skills such as wrestling or cross-country running. In these activities, the skilled performer learns to reduce or eliminate unnecessary movement or physical exertion. In addition to reductions in muscular forces through efficient regulation of the body's energy producing systems, individuals also learn to minimize the mental demands required for task attainment. Performers come to produce skills in more automatic fashion, with less conscious attention directed toward movement organization, and are then more able to direct mental resources to other features of the performance or the environment (a topic explored more fully in Chapter 6).
3. **Minimum movement time.** In many motor skills, the quality of performance increases with reduced time (or increased speed) of movement. Skillful performers of such motor skills as volleyball, soccer, baseball, running, and swimming all benefit from increasing the speed of their movements. Success in some sport skills, such as sprinting, is almost entirely determined by the speed of motor actions.

It should be noted, however, that some motor performances are not improved as movement speed continues to increase. In skills requiring considerable movement accuracy, such as hammering a nail or hitting a baseball, too much speed can result in decreased performance success. Attempting to hammer a nail too rapidly will result in misses (and perhaps a smashed finger or two), just as attempting to swing at a pitched baseball with maximum speed can result in a strike rather than a hit. These examples demonstrate one of the oldest principles in skill performance: the speed–accuracy trade-off, which we discuss in Chapter 4.

Limitations to Definitional Use

An important caution must be mentioned in applying Guthrie's definition distinguishing among individuals on the basis of varying skill levels. There is a tendency, when focusing attention too closely on aspects of performance quality, to limit the definition, and therefore the term *skill*, to only those performances of high quality or expertise. Only those skills carried out by highly

TABLE 2.1
Comparing Two Definitions of Motor Skill

	Classic Definition	Guthrie's Definition
Defining Characteristics	Goal-directed, learned behaviors accomplished primarily through contributions of the muscular system	Maximizes certainty of goal attainment while minimizing energy expenditure and movement time
Defining Perspective	Nature of the task	Quality of performance
Primary Question Addressed	What behaviors constitute motor skills?	What makes a person skillful?

skilled individuals may come to be seen as warranting research and scholarly attention. Too much focus on those qualities indicating high-level performance of motor skills may, as a result, lead us to neglect aspects of skill displayed by beginning or relatively ineffective performers, who may represent those individuals most in need of the movement specialist's attention.

Skills, Movements, and Abilities

Before concluding our consideration of the definition of motor skill, we need to clarify a few other terms that are either frequently used in its place or are incorrectly identified with it. Two terms are especially used in the literature when referring to motor skills; these are the terms *response* and *action*. Both of these terms can be used interchangeably with that of the term *motor skill* though each carries a slightly different theoretical connotation. The term **response** has the longest history of the two, and is rooted in psychological approaches to the study of human behavior going as far back as the early 1900s. The term is particularly favored by theorists emphasizing the behavioral or cognitive aspects of skill acquisition. (It should be noted that some theorists discourage use of the term *response*, feeling it indicates that skills are initiated exclusively by environmental stimuli rather than being voluntary behaviors. This being a valid caution, when using the term *response* in this text it is with the connotation that skills may be initiated both as responses to environmental stimuli, as well as to voluntary decisions). In recent years, the term **action** has emerged in common usage much more recently, especially by those theorists interested in the contributions of the environment and of the interaction of numerous systems in the control and acquisition of motor skills. Thus, *motor skill*, *response*, and *action* may be considered synonymous terms.

response: A term used synonymously with motor skill, especially by those favoring a cognitive perspective of motor behavior.

action: A term used synonymously with motor skill.

The term *movement* is frequently also used as a synonym for motor skill, as in "She has mastered the various movements required to be good at basketball." Movements are not the same thing as motor skills, however, and the two terms should not be confused and used interchangeably. Movements refer to the behavioral characteristics of bodily elements. The change in position of an individual limb or body segment is a **movement**. Movements are the constituent parts of a skill. Motor skills are assembled through a collection of movements organized together to manifest a complex action directed toward the accomplishment of a specific goal. Further, a particular motor skill can be accomplished through a variety of different movements. The movements executed to run on an indoor running track, on a sandy beach, or on an incline are different, yet each contributes to the skill of running.

movement: A change in the position of limbs or body segments; the behavioral components used to assemble motor skills.

Ability is another term frequently used incorrectly to refer to motor skills. Abilities are stable and enduring traits that are genetically inherited. Abilities can be thought of as the building blocks of motor skills, because they underlie the execution of movements and play a significant role in determining a person's capacity to learn and perform motor skills. Examples of motor abilities are reaction time, hand-eye coordination, and speed of limb movement. (It should be noted that, as with the term *response*, the term *ability* also reflects specific theoretical assumptions, leading some contemporary theorists to disregard its use altogether.) We will consider the topic of abilities in more detail in Chapter 8.

ability: A genetically endowed trait underlying the performance of motor skills.

THE STUDY OF MOTOR SKILLS

The study of how motor skills are controlled, as well as what methods are the most effective when instructing them, is grounded in the way we conceptualize motor skills and in the kinds of questions we ask. In the following section, we examine the three components of motor skills studied by movement scientists.

The Three Components of Motor Skills

What are the components influencing the performance of motor skills? What can be observed and studied? Newell (1986) has offered an influential analysis of these questions. In his analysis, he suggests that three components of motor skills influence their performance, and that all three must be taken into account for the fullest understanding of motor skills. These components include the person performing the skill, the task that is performed, and the environment in which the skill is performed (see Figure 2.2). In the simplest terms, the conceptualization of motor skills must take into account the who, what, and where of skills. Although motor skills are a composite of all three components, each component addresses unique features of skill performance, and each therefore lends itself to the study of a unique set of questions.

The Person

The attributes of individual persons play a significant role in shaping the performance of motor skills. Each person brings a unique composition of innate abilities, physical characteristics, psychological traits, previous skill-learning experiences, age, and motivation to the performance of motor skills. Such personal features can interact in different ways with how individuals experience different practice arrangements, different types of instruction and feedback, and other training arrangements. By studying such individual and training differences, movement scientists can gain information concerning the properties of skills and of the processes responsible for their learning.

The Task

The nature of the task is the second component shaping the performance of motor skills. Motor skill tasks vary widely in their goals and in the movement demands placed upon performers. Some tasks must be performed under a variety of conditions, such as driving in traffic, whereas others are performed consistently from one performance context to the next, such as shooting basketball free throws. Tasks also vary relative to the perceptual demands they place upon individuals. Many motor

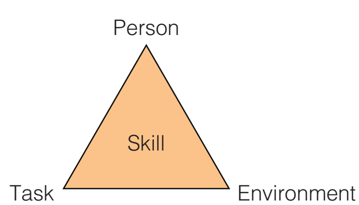

FIGURE 2.2 The Study of Motor Skills Encompasses Three Components Influencing Performance

skills have high perceptual demands. Baseball players must accurately determine the speed and path of a pitched ball when batting, and hockey goalies quickly discern the movement patterns of an opposing team rushing the net, for example. Other tasks require the manipulation of implements for successful performance. Bowling, hammering nails, and using a prosthesis all require coordinating bodily movements within constraints imposed by external objects. The rules of sports skills may also constrain a person's movements and influence the quality of task performance.

The Environment

The third component influencing skill performance is the environment in which a person executes the skill. Where will a motor task be performed? What is the environmental context of performance?

Skills may be performed within environments that are predictable or unpredictable, similar or dissimilar to practice conditions, recreational or competitive. Skills may also be performed alone or in the presence of others, who can include other performers as well as spectators. Physical conditions of the performance context may also influence performance characteristics. Lighting conditions, temperature, wind, and gravity can substantially alter the performance of many skills.

Ultimately, the fullest understanding of motor skills derives from an appreciation of the interaction of all three components contributing to their performance.

CHARACTERISTICS OF MOTOR SKILLS

Having defined motor skills, we next inquire into the characteristics common to motor skills. What features do all motor skills share in common? This is far from a question for mere speculation. In approaching the scientific study of motor skills, our assumptions, theories, and findings must remain embedded within the shared framework of such characteristics. Indeed, any theory or research finding must ultimately be tested by its ability to adequately address, and shed light upon, such shared characteristics. In identifying the characteristics common to all motor skills, Sheridan (1984) has proposed that any

BOX 2.3 Can You Identify the Components of Motor Skills That Influence Performance?

The performance of any motor skill is influenced by three distinct skill components. The environment in which a skill is performed can both facilitate and limit performance possibilities. Likewise, the nature of the task, including equipment and rules, can assist as well as limit performance. Finally, qualities inherent in the person performing the skill, such as previous experience, physical fitness, and motivation, play a significant role in skill performance. For the following activities, can you think of something about each of these three components that would act to constrain or limit performance, as well as something that would facilitate the quality of performance?

- Riding a bicycle
- Catching a Frisbee
- Walking on crutches
- Serving a volleyball
- Standing from a chair
- Driving a car

List one factor that might limit, as well as one that might enhance, performance of each skill for the skill components of environment, task, and person.

adequate theory of motor skills must address at least four essential characteristics common to all motor skills. These include motor equivalence, motor variability, motor consistency, and motor modifiability.

Motor Equivalence

Humans are highly flexible in the ways they can move to meet environmental demands (Lashley, 1930; Flash and Hogan, 1985). Flexibility of action is achieved by recruiting different muscles and joints to achieve the same skill goal (by organizing different movements to accomplish the same skill goals). For example, you can catch a ball with either your dominant or nondominant hand, turn on a light switch using your elbow when your hands are filled with packages (you can even use your nose), or sign your name holding a pen between your teeth while writing on a piece of paper. These are examples of skilled action accomplished with effectors we would not normally use to complete a given motor skill, but which nonetheless can often be done with great effectiveness even when we may never have attempted the action in exactly the same way before. This capacity to accomplish the same environmental skill goal in many

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Humans are capable of accomplishing the same skill goal in many different ways, a capacity known as motor equivalence.

motor equivalence: The capacity to produce many different movement patterns to accomplish the same action goal.

different, and often quite varied, ways is referred to as **motor equivalence**, and denotes the many equivalent ways we can move and still accomplish the same action goal. Although we typically accomplish such equivalent movements with considerable ease, the explanation of how we do so remains a complex and debated question among motor behavior theorists (Kelso et al., 1998).

Motor Variability

The uniqueness of human action—the fact that no two skills are ever accomplished in exactly the same way—is a second characteristic of human motor skills. Even when we watch a highly skilled performer completing successive repetitions of the same stereotypical skill—such as a tennis player hitting balls projected by a ball machine—the repeated actions are never completed in exactly the same way. Slight variations are evident, for example, in how the body is positioned prior to contacting the ball, in the kinematic patterns of limb movements during skill execution, and in the kinetic forces generated to accomplish the skill. More striking yet, the same neural pathways are never used successively in completing the same skill, nor are the same motor units recruited and patterned the same way to control muscular forces. Even when movement skills may appear nearly identical to an observer, at the neurological level they are markedly different, with movements organized and assembled through vastly different architectures of neural routes, synaptic impulses, and collectives of muscle fibers (see Chapter 3). This suggests that the movement patterns underlying motor skills are not rigidly constructed, but that new solutions to movement problems must be found each and every time a skill is

BOX 2.4 In How Many Different Ways Can the Goal of a Skill Be Accomplished?

An old saying goes that "All roads lead to Rome." But can many movements lead to the same skill goal? Motor equivalence refers to the capacity of humans to recruit different effectors, and to organize movements in different ways, in order to accomplish the same movement goal. Most skill goals can be accomplished in an almost infinite variety of ways. In a first-round play-off game concluding the 2007 football season, the Green Bay Packers quickly gave up two touchdowns to the Seattle Seahawks and appeared on the verge of being eliminated from further competition. After rallying back, though, the Packers were down by only 4 points. Then Brett Favre, the Packer quarterback, drove his team to within 20 yards of a go-ahead score. But after three failed plays, and with a fourth down and still 20 yards to go to the end zone, the Packers' chances looked bleak. As the ball was snapped, the Packers' play-off hopes rode on a single play. Favre went back to pass but was instantly surrounded by charging Seahawk defenders who chased him out of his protective pocket. Scrambling to avoid being tackled, Favre stumbled and was falling toward the turf. As he fell forward, he managed to twist his body a full 180 degrees so that his back was toward the ground and his body fully stretched out. A few inches before hitting the turf, Favre flipped the football across his body with a backhanded toss into the end zone, where a waiting receiver, Greg Jennings, caught it for a game-winning touchdown.

How many times do you suppose that Favre had practiced throwing the football in that particular way previously? The fact that he had almost certainly never done so, yet could organize his motor system to accomplish a well-learned skill in an entirely new and different way, a phenomenon called *motor equivalence*, is one of the most amazing movement characteristics that humans possess.

performed, even if that skill has been performed in more or less the same way thousands of times previously. This phenomenon is called **motor variability**, and is one of the most challenging problems in the study of motor skills.

motor variability: No two movement patterns, even of the same skill, are ever produced in exactly the same way.

Motor Consistency

Even though all motor skills are unique, as we have just seen, still we learn to move in skillful ways. That is, even though we never produce a skill in exactly the same way twice, in those skills for which we practice and become good, we are highly consistent from one time to the next in achieving the same outcome. A highly skilled baseball pitcher never uses the same neural pathways in throwing a fastball (even after throwing perhaps hundreds of thousands of fastballs), yet his fastball is consistent in striking out batters. This ability to accomplish the same movement goal, which is improved through experience and practice, is termed **motor consistency**. How we learn to produce such skilled actions, given the variability of each movement, is a problem motor learning specialists must answer if their theories of motor control and learning are to have the greatest explanatory power (see discussion of the skill acquisition problem in the following section of the chapter).

motor consistency: The capacity to achieve the goals of motor skills consistently; the capacity of the human motor system to learn.

Motor Modifiability

The final characteristic for which any theory of motor skills must account is that of a skilled performer's ability to modify an action once its execution has begun. Observing any athletic performance involving the need for athletes to quickly react to rapidly changing game situations will provide many examples of this characteristic. Examples could include, for instance, a baseball player who begins to swing at a pitched ball but then quickly lets up, stopping his swing when it becomes obvious the ball is not in the strike zone, or a basketball player starting to take a shot and then quickly changing her actions to pass the ball to a teammate when a defender covers her too closely. The ability to change an action quickly once it has begun is termed **motor modifiability**. Again, as with the other characteristics listed here, it is easily accomplished—often seemingly effortlessly—but a complex phenomenon when we begin to attempt a scientific explanation of it.

motor modifiability: The capacity to alter a movement pattern to achieve a new action goal.

In summary, the characteristics listed above and common to all motor skills present challenging problems in the study of motor skills, even when in practice their solution may seem achieved with considerable ease. This leads us to a consideration of the problems confronting us in the study of motor skills.

FOUR PROBLEMS IN THE STUDY OF MOTOR SKILLS

In the study of motor skills, four problems occupy a central place (Rosenbaum, 2010). None of the characteristics among motor skills presented above, for instance, can be adequately addressed without some explanation concerning these four persistent problems. Indeed, the major theories that guide research concerning motor behavior are largely attempts to provide satisfactory answers to these central questions. The fact that there are different theories is testimony to the complexity of these problems, and to the ongoing lack of a consensus in how they should be answered. These four persistent problems include (1) the degrees of freedom problem, (2) the perceptual-motor integration problem, the (3) serial-order (timing) problem, and (4) the skill acquisition problem.

The Degrees of Freedom Problem

unit of action: A specified component of movement that can be used repeatedly in various actions, producing essentially the same results.

degrees of freedom: The number of dimensions in which a system can independently vary.

One of the greatest challenges facing movement scientists concerns answering the question of how various **units of action** (e.g., joints, muscles, motor units, cells) are organized and controlled in order to accomplish skill goals. Specifically, how does a person, in response to his or her environment, coordinate and control a complex system of bony segments, linked by joints and layers of musculature, that is capable of moving in a variety of different ways. Recall that in the performance of any motor skill, there are many ways the motor system might be organized in order to produce movements capable of achieving skillful goals (i.e., motor equivalence). Only one of many alternative means of achieving a desired outcome must be selected, however. The question is: How is this accomplished?

The term **degrees of freedom** is used to describe the number of different ways in which any given unit of control is capable of being organized. Stated more precisely, it is the number of dimensions in which a system can independently vary. The term *independent* is critical to our understanding here. Simply, it means that regardless of the value one thing takes on (e.g., muscle A contracts a certain amount), another thing within the same system is still free to take on any of the values of which it is capable (e.g., muscle B is free to contract to any value, or to not contract at all—it is not limited by the value to which muscle A has contracted).

We can consider the degrees of freedom available to an individual as all of the possible choices for organizing desired motor skills. We can further specify these available degrees of freedom at various levels of analysis. If what we control during movement are the joints, then to move the arm, for example, would require seven degrees of freedom. Three degrees of freedom are available at the shoulder (it can move up and down, side to side, and rotate), two at the elbow (it can flex and extend and it can rotate), and two at the wrist joint (it can move from side to side and it can flex and extend). If we go a step further and consider muscles as the unit that is controlling movement, the number of degrees of freedom rises dramatically. In order to move the same arm successfully, we must now regulate a minimum of 26 degrees of freedom: 10 muscles at the shoulder joint, 10 more at the elbow joint, and 6 controlling the different movements of the wrist joint. If this analysis of an arm movement is extended to the unit of action of motor units, the estimated number for the degrees of freedom available rises exponentially—into the thousands (see Box 2.5). The greater the number of degrees of freedom that must be controlled, it should be pointed out, the greater the complexity of the problem that must be solved by the motor system.

Over half a century ago, the Russian physiologist A. N. Bernstein recognized that human coordination emerges from the accumulated involvement of many redundant degrees of freedom that underlie multijoint movements. The many different ways in which movements might be organized in order to accomplish skill goals is made possible by a large surplus of degrees of freedom available. How one pattern of organizing these redundant degrees of freedom is selected rather than another has come to be referred to as the **degrees of freedom problem**. In initially formulating this problem, Bernstein argued that the computational demands placed upon the central nervous system were too great for it to be considered the sole executor of movement control. The degrees of freedom problem first formulated by Bernstein remains at the core of today's contemporary theorizing concerning the control of human movement.

degrees of freedom problem: How the many degrees of freedom available in the human motor system are controlled to produce a particular movement.

The Perceptual-Motor Integration Problem

Skills do not occur in a perceptual vacuum. Perception is the process of acquiring, selecting, interpreting, and organizing sensory information. Skill movements are guided by sensory information arising from both the environment and performer's body. How perceptual information is coupled with bodily movement in order to achieve skillful actions is one aspect of the perceptual-motor integration problem. For example, in order to catch a tossed object, the

BOX 2.5 How Many Ways Can You Touch Your Nose?

The large redundancy of degrees of freedom available in the human motor system makes possible tremendous flexibility in people's movement capabilities, but also presents a challenging problem to movement scientists attempting to understand the control of movement. This problem can be illustrated with a simple exercise (Rosenbaum, 1991). To perform this exercise, touch the tip of your index finger to the tip of your nose (go ahead and complete this).

No doubt, you performed this exercise with little effort, but consider the computational demands it placed upon your central nervous system. If we consider just the arm as our basic unit of analysis, and the unit of action as the joints involved in moving the arm, then there are seven degrees of freedom that must be controlled in touching your nose. That is, the shoulder is free to assume values in each of three dimensions (horizontal, vertical, and twisting), the elbow in two dimensions (it can bend and twist), and the wrist also in two dimensions (up and down and side to side). Consider, though, that each way a particular joint might vary can be coupled with every way both of the other joints might vary, so that in reality there are 12 distinct movement combinations made possible by the degrees of freedom in the arm (i.e., the number of degrees of freedom for each joint multiplied through, or $3 \times 2 \times 2$). If we extend our analysis to the level of muscles, however, the challenge will appear to become somewhat greater. Now there are 26 degrees of freedom in the arm (10 muscles control shoulder movements, 10 for the elbow, and 6 for the wrist). Calculating the number of different muscle activation patterns possible, there are 600 different contraction/no contraction combinations among the 26 individual muscles ($10 \times 10 \times 6$). That is, there are 600 basic coordination patterns available to select from in touching your nose.

One final level of analysis must still be considered. Remember that the nervous system controls both joints and muscles indirectly; direct control is of motor units. If we take a conservative estimate and assign a value of 100 motor units to each muscle (there would be more in our example), then the 26 muscles controlling the arm represent 2,600 degrees of freedom at the motor unit level of analysis. Again, because motor units are also trajectory of the object must be determined and related to the current position of the hand that will be used to catch it. The position of the fingers, as well as the "firmness" with which the catching limb is maintained, must also be adjusted depending upon the perceived size, shape, and velocity of the tossed object. Moreover, these adjustments must be initiated prior to contact with the tossed object. Thus, the relevant aspects of a person's environment must be perceived and effectively coupled with movements of the catching limb and hand to successfully accomplish the goal of intercepting and grasping the tossed object. A persistent problem in the study of motor skills is to understand how the highly coordinated movements of limbs and bodily segments are effectively coupled with sensory information to produce the exquisitely executed skills of which humans are capable. This is referred to as the **perceptual-motor integration problem.**

perceptual-motor integration problem: The intellectual problems arising when attempting to explain how perception is coupled with human movement to produce motor skills.

Although perception guides movement, movement also influences perception. One obvious reason for this is that movement transports sensory receptors to new locations, thus benefiting perception. Turning your head supplies additional visual information concerning the environment, thus enriching and

free to take on any individual value in relation to any other motor unit (each can be "on" or "off" according to the all-or-none law), there are within the movement system of the arm *600 million* possible combinations available when recruiting motor units to touch your nose (1,000 × 1,000 × 600). How you selected a particular combination from the many possibilities available is still debated by movement scientists, though fortunately it will not prevent you from scratching your nose should you have an itch. A summary of our calculations is shown in the accompanying table.

	Units of Action		
	Joints	Muscles	Motor Units
Shoulder	3	10	1,000
Elbow	2	10	1,000
Wrist	2	6	600
Degrees of freedom in three-joint system	7	26	2,600
Total number of possible combinations of degrees of freedom within three-joint system	12	600	600,000,000

benefiting perception. Walking to a new location allows you to see and hear more of what is present in the environment. Exploring objects with your hands allows you to better perceive their shapes and surface textures.

Movement affects perception in even more subtle ways, however. There is growing evidence that perception is altered by the movements that humans are capable of producing (Proctor and Dutta, 1995; Vickers, 2007). When people view a cluttered environment through which they must navigate, for instance, they are most likely to perceive those environmental features that afford the greatest opportunity for passage given their movement capabilities (such opportunities are called **affordances**). Individuals with poor or limited movement skills are most likely to perceive features within the environment that provide for the greatest ease of passage, whereas those with a greater repertoire of movement skills are the most likely to perceive features indicating a more difficult but shorter path across the cluttered space, for example. In other words, a person's movement capabilities play a role in what he or she perceives in the environment, supposedly providing the perceptual cues that will be of the greatest benefit.

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

Although perception and movement are intricately linked and mutually dependent upon one another, there is considerable debate concerning how they are linked. Some theorists posit that higher-order cognitive representations of skills mediate between perception and movement, viewing perception as "information" used to plan and carry out movements. Other theorists emphasize a direct link between perception and action, seeing little need for additional mediation (Gibson, 1966, 1979). Regardless of which theoretical perspective is assumed, however, the coupling between perception and movement remains one of the most challenging problems facing motor skill theorists and researchers.

The Serial-Order (Timing) Problem

Whenever skills require the sequencing of discrete movement elements, some means of organizing their execution is required (Proctor and Dutta, 1995). A dancer rhythmically linking dozens of individual movements into delicate routines of choreographed precision and grace, a typist whose fingers appear to fly from letter to letter on a keyboard without error, the competitive swimmer perfectly coordinating patterns of arm circles and leg kicks while racing through the water—all illustrate the human capacity for stitching individual threads of movement into the many patterns representing the fabric of motor skills.

We need not look only to expertly performed skill examples such as those of the dancer, typist, or swimmer to observe the intricate timing involved in most motor skills, however. Daily activities such as walking, speech, and dressing are also comprised of the linkage of many precisely timed and ordered submovements. The **serial-order problem** consists in how the ordering and timing of the various subelements that comprise motor skills are controlled. One possible explanation is that skills rely on some sort of stimulus–response mechanism so that sensory feedback from one response acts to initiate the following response in a sequence. This notion is referred to as *linear chaining*. A major weakness in the linear chain notion, however, is that no single motor element acts to elicit the same response in every skill situation, but may indeed be followed by many different responses depending upon the particular situation. This weakness, first

serial-order problem: The problems arising in attempting to provide an adequate explanation for how the order and timing of movement elements forming motor skills are organized and controlled.

pointed out many years ago by Lashley (1951), has led to the search for alternative explanations for how motor acts are timed. Two major alternatives have been advanced, with both a hierarchical model based upon cognitive control and a constraints-led model based upon the interaction of the actor and environment proposed. Although theoretically different, both models have provided revealing insights and continue to advance our understanding of how the timing and sequencing components of human motor skills are controlled.

The Skill Acquisition Problem

In presenting the characteristics common to all motor skills, we have stated a seeming contradiction; that is, skills exhibit motor variability—even when performed in highly stereotypical fashion, they are never organized in exactly the same way twice. On the other hand, skills exhibit motor consistency. Through repeated experiences, people become more capable of meeting the goals of a skill—they become more skilled. How does such learning take place given the variability inherent in skilled behaviors? This question represents the **skill acquisition problem**.

skill acquisition problem: An intellectual or research problem arising in attempting to explain how motor skills are learned.

To the movement practitioner, this is probably the most critical problem in the study of motor skills. Certainly, an adequate understanding of how motor skills are acquired is critical to the design of effective practice experiences. To the movement scientist also, though, the question of how motor skills are acquired presents many research and theoretical challenges. The general problem of skill acquisition is really expressed as a series of subproblems. Among the most intriguing and widely researched are the following:

1. What are the underlying processes responsible for skill learning?
2. How are skills represented in the nervous system? Or are they?
3. Are some skills innate, or are all skills acquired through experience or practice?
4. Do people pass through identifiable stages when learning skills? If so, are they the same for everyone?
5. As motor skills are acquired, what changes occur within individuals?
6. What is the optimal way to schedule practice experiences?
7. What kind of instructions prove of the greatest benefit to learners? Of what information are learners in the most need?
8. Is there an upper limit to how proficient an individual can become in a given skill?
9. Why do individuals differ in their capacity for learning different skills?
10. How does the learning of one skill influence the learning of other skills?

Answers to these questions, as well as the broader question concerning the primary mechanisms responsible for skill acquisition generally, remain among the most challenging to movement scientists.

THE CLASSIFICATION OF MOTOR SKILLS

As is clear from our discussion in this chapter, motor skills represent a diverse collection of movement behaviors. Motor skills include activities as different as knitting and Olympic weight lifting, downhill skiing and brushing your teeth, or fly-fishing and ballet. Such striking differences among the behaviors defined as motor skills can easily lead to confusion, especially when we wish to communicate about important similarities or differences among motor skills. What is needed is a method of classifying motor skills based upon a limited number of relevant features that can provide for meaningful grouping as well as effective communication. In the study of motor skills, two methods of classification, one-dimensional and two-dimensional systems, are widely used.

One-Dimensional Classification Systems

In a one-dimensional classification system, the phenomena of interest are classified on a continuum between two polar opposites. For example, temperature can be classified on a continuum running between the polar opposites of hot and cold, mood between polar opposites of sad and happy, or political identity between polar opposites of liberal and conservative. When applying a one-dimensional system to the classification of motor skills, three dimensions of performance or of the performance context are identified. These include (1) the stability of the environment in which a skill is performed, (2) the temporal features of the skill relative to its beginning and ending, and (3) the precision of movement required in accomplishing the skill. All motor skills can be classified along each of these three dimensions.

The Classification of Motor Skills Based upon the Stability of the Environment

One system for classifying motor skills is based upon the stability of the environment in which they are performed. Here, environment refers to the context in which a person performs, as well as any object or objects upon which the person acts. Motor skills are classified as either closed or open, depending upon the predictability of the environment.

If the environment in which a person performs remains relatively constant from one time the skill is performed until the next, we classify the skill as a **closed motor skill**. Typing, for example, is a closed skill. The placement of the letters on a keyboard does not change from one keyboard to the next. Closed skills have the important feature that the environment or object acted upon waits, in effect, to be acted upon by the performer. You decide when to start typing, as well as when to stop and then start again. For this reason, closed motor skills are sometimes referred to as **self-paced motor skills**. Examples of closed skills include target shooting, writing, using a knife and fork, shooting basketball free throws, pitching horseshoes, and painting a wall.

closed motor skill: A skill in which action occurs in a stable and predictable environment.

self-paced motor skill: A commonly used term denoting a closed motor skill.

open motor skill: A skill for which the object acted upon or the context in which action occurs varies from one performance to the next.

As opposed to closed skills, an **open motor skill** is performed in a changing, unstable, and unpredictable environment. A person does not know from one attempt of a skill until the next how an object or the performance context may change and require modifications to the way in which the skill must be performed. Although free-throw shooting is a closed motor skill in the sport of basketball, dribbling down court during a basketball game is an open skill. In this case, the basketball player must react to movements of opposing players, as well as those of teammates, all the while responding to constantly changing game situations. Proper skill execution, or even whether a skill should or should not be executed, cannot be accurately predicted and planned for in advance. For this reason, open motor skills are also referred to as reactive motor skills. Examples of open motor skills include open-field running in football, driving in traffic, chasing a dog, downhill snow skiing, dodging water balloons, and surf boarding.

How would you classify bowling? Is it a closed or an open motor skill? If you consider only the first ball in each frame, it is certainly closed because everything about the environment remains constant from one attempt to the next. But what about the second ball of each frame? For two kinds of bowlers, nothing changes: an expert bowler rolling a 300 game, and a beginner bowling all gutter balls. For both types of bowlers every attempt presents the same situation—all 10 pins are standing. For most bowlers, however, the second ball of each frame will present a somewhat different situation than the initial ball. Some of the pins will have been knocked down, although not the same ones each time. Sometimes nine pins will remain standing, and other times only a single pin; sometimes pins will remain standing on the right, sometimes on the left; and sometimes on both sides of the lane—a dreaded split! In each case, something has changed about the environment. How, then, should we classify the second ball in a frame?

Although some features of the environment in our example of second balls within frames of bowling may change, it should be clear that many more remain predictable. The ball is still the same. The lane on which the ball is rolled does

Chris Willson/Alamy

Mike Kemp/Jupiter Images

In open motor skills performers must react to unpredictable and changing conditions (left), while closed motor skills are performed within stable and predictable environments (right).

not change. And even though the exact arrangement of pins may vary, they do not do so in a way that drastically alters the movement pattern required to successfully bowl the ball and knock down each changing pin arrangement. More importantly, regardless of the number of pins standing, the skill is still self-paced—the performer can act when ready. So we can say that even a split presents a relatively closed environment where most features remain the same as for other balls thrown in the game. Thus, considering skills on a continuum ranging between closed and open environmental features, the second ball of a bowling frame remains closer to the closed end of the continuum than to the open end. Regardless of the particular arrangement of pins in the environment, bowling, in general, is considered a closed motor skill.

The closed–open classification system has been popular in instructional skill settings. An important reason is that it is relatively easy to classify skills in this fashion, and skills in each category follow common principles of instruction that teachers and therapists can readily apply. The closed–open distinction is also common in motor skills research, because findings relative to each category easily translate into real-world applications (see Figure 2.3).

The Classification of Motor Skills Based upon Temporal Predictability

A second way of classifying motor skills in a one-dimensional system is on the basis of the predictability of their beginning and ending points. Based upon these temporal features, motor skills are classified as being discrete, continuous, or serial.

Some skills, like hitting a baseball, have specific beginning and ending points. A batter must begin swinging as the ball approaches home plate, and once the swing is completed, all relevant action is over. Skills of this type, which have clearly identifiable beginning and ending points, are classified as **discrete motor skills.**

discrete motor skill: A motor skill in which the beginning and ending points are clearly defined.

Unlike batting in baseball, not all discrete motor skills have both a forced beginning and ending point. Some, like hitting a golf ball rather than a baseball,

Closed Skills ⟵		⟶ Open Skills
Predictable performance context	Semi-predictable performance context	Unpredictable performance context
Basketball free throw	High jump	Mountain biking
Typing	Chopping wood	Wrestling
Springboard diving	Driving on a quiet road	Driving on a busy road
Painting a wall	Passing a basketball to a teammate in a game	Defending a goal in ice hockey

FIGURE **2.3** Classification of Skills as Closed or Open

Source: Created by author.

have arbitrary beginning points—the performer can wait until ready to hit the ball. The ending point to hitting a golf ball, however, is still forced by the completion of the swing and striking of the ball (this is, of course, the distinction between open and closed skills). Discrete skills are also typically completed quickly, usually lasting from a fraction of a second to no more than a few seconds.

A discrete skill is one that exhibits well-defined beginning and ending points, and is typically executed in a relatively brief period of time. We can add that the beginning point is not always temporally predictable, though the timing of the action is often rigidly fixed and highly predictable. Examples of discrete motor skills include serving a tennis ball, throwing darts, standing from a sitting position, ringing a doorbell, jumping over a fence, and flipping a coin.

continuous motor skill: A motor skill in which the beginning and ending of action is arbitrary.

A **continuous motor skill** is one in which both the beginning and ending are arbitrary and unpredictable. Continuous skills are often (though not always) repetitive and rhythmic in nature—like walking and swimming, for example. A different but important class of continuous skills includes tracking skills, such as steering an automobile or keeping a stylus in contact with the target on a rotary pursuit task, which require the performer to continuously monitor the external environment and correct actions in an ongoing fashion. The point in either case is that the temporal dimensions of the tasks involved (beginning and, especially, ending points) are arbitrary and cannot be determined prior to the completion of an action. The individual decides when to end a continuous skill, and frequently when it will begin, also. Examples of continuous skills include riding a bicycle, running, tracking a moving target on a computer screen using a joystick, stirring hot coffee with a spoon, and flying a kite.

An interesting problem confronts us when deciding upon classifying motor skills on the basis of temporal considerations. Consider the skill of typing, for example. It is clear when watching a beginning typist that the actions involved are discrete in nature. That is, the beginning typist deliberately strikes a single key at a time—"C" for example—stops to search for the next key and then produces another discrete action—striking "A" in this example—then pausing to search again before striking another key—"T" to complete the example "CAT"—and so on and on. When those learning to type, it is clear that their actions represent a series of discrete acts. What about the same skill with an advanced typist? The expert's fingers seem to race effortlessly over the keyboard without pause. It is tempting to say the expert typist is performing a continuous skill. The problem is that a skill cannot be classified as two different types of skill, in this case both discrete and continuous, depending on a performer's skill level. (Remember that it is the skill itself, not the performer's skill level, that is classified in one-dimensional systems).

serial motor skill: A motor skill composed of a series of discrete skills such that the integration of each discrete component into a continuous movement pattern is crucial to performance success.

The solution is a special classification for skills such as typing. Skills that require a series or sequence of discrete elements, like typing, are classified as **serial motor skills**. Serial skills are discrete skills that are linked together (often through a stimulus-response connection) and performed in a sequenced action, often so rapidly that they mimic a continuous skill. Examples of serial skills include hammering a nail, shifting gears in an automobile, a dance routine, playing the piano, brushing your teeth, and dribbling a basketball. It should be noted that some serial skills involve a simple repetitive or even rhythmic sequencing of the same action, such as dribbling a basketball or hammering a nail. Other serial skills involve the sequencing of different discrete skill elements in an exact order, such as typing or shifting gears in an automobile.

Although discrete skills have clearly predictable ending points, and the completion of continuous skills is arbitrary, the temporal predictability of a serial skill's ending point may be either predictable or arbitrary. For serial skills consisting of a series of different subskills, such as shifting gears in an automobile, the completion of the skill is highly predictable, whereas for highly repetitive actions like dribbling a basketball the performer decides upon the ending point (see Figure 2.4).

The Classification of Motor Skills Based upon Movement Precision

A third one-dimensional system for classifying motor skills is based on the precision of the movements required for completing the skill. (In defining this dimension, some writers prefer to focus upon the size of the primary musculature required in performing skills.) Within this one-dimensional system, motor skills are classified as being either fine or gross.

fine motor skill: A motor skill in which the precision of movement is the primary requisite for performance success.

Skills such as threading a needle that place primary emphasis on the precision of movement, rather than upon muscular effort, are labeled **fine motor skills**. Fine motor skills are typically accomplished by recruiting small muscle groups such as those of the fingers, hands, and forearms; may place a high premium on hand-eye coordination; and require little muscular force or energy to successfully accomplish. Examples of fine motor skills include handwriting, sewing, using chopsticks, buttoning a shirt, repairing watches, using precision tools, and operating a rotary-pursuit apparatus in a motor learning laboratory. In all of these cases, it is the precision of the movement itself, and not how forcefully it is done, that results in successful performance of the skill.

gross motor skill: A motor skill in which the contributions of muscular force are the primary requisite for performance success.

Gross motor skills are those that require the use of relatively large musculature in producing an action. Fundamental motor skills such as walking, running, leaping, jumping, throwing, balancing, and climbing are gross motor skills. Gross motor skills typically involve many muscle groups and, frequently, movement of the entire body. Although many sports skills classified as gross motor skills may require exquisite coordination to accomplish,

Discrete Skills	Serial Skills	Continuous Skills
Tennis serve	Triple jump	Water skiing
Flipping a coin	Paddleboarding	Flying a kite
Catching a ball	Shifting car gears	Brushing your teeth
Throwing a dart	Playing the drums	Rowing a canoe

FIGURE **2.4** Classification of Skills as Discrete, Serial, or Continuous

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Image Source/Jupiter Images

Fine motor skills require a high degree of movement precision, and typically require the manual manipulation of objects and good hand-eye coordination.

the contributions of muscular force outweigh demands on movement precision in accomplishing the action. Examples of gross motor skills include standing from a chair, catching a football, doing somersaults, performing a *tour en l'air* in a ballet program, blocking in volleyball, and climbing a ladder.

Fine and gross skills form a continuum marked by the gradual shift of importance placed on either movement precision or force production in accomplishing the goals of a skill (see Figure 2.5).

Gentile's Two-Dimensional Taxonomy for Classifying Motor Skills

When making decisions about appropriate skill activities, motor skill instructors must frequently take into account the performance demands placed upon individuals. Although one-dimensional classification systems effectively discriminate among different classes of motor skills based on several important task considerations, they are less effective in delineating among skills based upon performance demands. What is often required is a system for grouping motor skills into categories based upon similar performance characteristics (recall here the analogous situation with the two definitions of motor skill

Fine Skills ⟵	⟶	Gross Skills
Knitting	Steering a car	Pole vaulting
Buttoning a shirt	Taping an athlete's ankle	Changing a tire
Drawing	Putting in golf	Weight lifting
Repairing a watch	Shooting pool	Playing tug-o-war

FIGURE 2.5 Classification of Skills as Fine or Gross

Source: Created by author.

discussed at the beginning of this chapter, with the classic definition assuming a task perspective and Guthrie's definition taking a performance perspective in defining motor skills).

In response to this need, Gentile (1972, 2000) broadened the categorization of motor skills into a two-dimensional system comprising a taxonomy having 16 skill categories (a taxonomy is simply a classification of things into groups having similar features). Gentile's original purpose in creating her taxonomy was to provide a tool for physical therapists to more effectively evaluate the motor skill proficiencies of their patients and to determine appropriate treatment protocols. Although Gentile's taxonomy was originally designed for use in physical and occupational therapy, its use has broadened to encompass instructional design considerations in many movement-related fields and today is used in sports, physical education, performing arts, and industrial settings. The taxonomy underpins evaluation and instructional decisions across a wide spectrum of applications and provides an important tool for movement practitioners in all fields involving the acquisition and performance of motor skills.

Gentile's taxonomy starts by classifying all skills on the basis of two dimensions influencing performance. These include the demands placed upon individuals by the environment as well as those requirements imposed by the task itself.

BOX 2.6 Can You Classify Skills According to the One-Dimensional Classification System?

The one-dimensional classification system for motor skills is widely used among professionals in many movement-related fields and provides a common vocabulary for communicating about motor skills. To test your ability to use this classification system, see whether you can classify the following skills into each of the three one-dimensional systems presented in this text. For each skill, decide whether it is a (1) open or closed skill; (2) discrete, serial, or continuous skill; and (3) fine or gross skill.

- Assembling a puzzle
- Playing billiards
- Chopping wood
- Dribbling a yo-yo up and down
- Playing a video game
- Playing the banjo
- Punting a football
- Texting
- Sport-wall climbing
- Walking on crutches

Environmental Demands

The first dimension in Gentile's taxonomy considers the demands placed upon individuals by the environment in which a skill is performed, and is labeled Environmental Demands in the taxonomy (see Table 2.2). Two characteristics of the environment are considered in the taxonomy. Gentile referred to these as regulatory conditions and intertrial variability.

regulatory conditions: Features of the performance environment that determine how a skill must be performed in order to be successful.

Regulatory conditions refer to those features of the environment that are relevant to how a skill must be performed. Regulatory conditions specify and constrain the actions a person must execute. Features of the performance environment including spatial dimensions, obstacles and the arrangement of objects within the performance space, the nature of the supporting surface on which a skill is performed, wind and lighting conditions, and the presence of other people are examples. An important distinction in Gentile's taxonomy is whether regulatory conditions are stationary or in motion. As this description indicates, stationary regulatory conditions are stable and do not demonstrate relevant change within the environmental context. The initiation and timing of action is, given stationary regulatory conditions, under the control of the performer. In-motion regulatory conditions, also as the term implies, refer to those conditions in which relevant features of the environment change or are in motion during the performance of a skill, imposing how the initiation and timing of action must be controlled. The distinction between stationary and in-motion regulatory conditions in Gentile's taxonomy is, in this case, the same as the one-dimensional system distinction between closed and open skills. Gentile's taxonomy extends the distinction between closed and open skills further, however, by considering also the notion of intertrial variability.

A second feature of environmental context demands classified by Gentile is whether regulatory conditions remain the same or change from one performance attempt to the next, referred to as intertrial variability. Although many skills performed in stationary regulatory conditions show few if any environmental changes from one attempt to another (e.g., a basketball free throw), others are marked by both environmental stability and trial-to-trial environmental change (e.g., billiards). Likewise, in-motion regulatory conditions can also exhibit intertrial variability (e.g., driving on a busy street), probably the most typical situation, or little or no variability (e.g., stepping on to a moving escalator). In Gentile's taxonomy, intertrial variability is classified as being either absent or present.

Action Requirements

The second dimension classified by Gentile's taxonomy pertains to the actions required in performing a skill. Specifically, Gentile classified two aspects of a performer's bodily actions. These include what she termed *body transport* and *object manipulation* (see Table 2.2).

Body transport refers to whether a person must change location when performing a skill. Playing soccer and snow skiing both demand changes in a performer's spatial location. Some skills may involve bodily transport as the primary goal of performance (e.g., a 100-yard dash), whereas for others the requirement to change location imposes additional demands on other performance goals (e.g., moving to avoid a defender before taking a shot in basketball). Other skills require no change in location in order to accomplish the skill successfully (e.g., performing a sit-up, driving a golf ball).

In addition to considerations of body transport, a second essential feature of action requirements is whether the manipulation of an object, or of other individuals, is required when performing a skill. Many motor skills require the performer to manipulate objects (e.g., swing a golf club, throw a ball) or other people (e.g., wrestling, square dancing) when performing the skill. Although such manipulations are frequently accomplished using the hands, other body segments may also be involved (e.g., kicking a soccer ball, blocking in football). As with intertrial variability, object manipulation is classified as being either absent or present.

Gentile's 16 Skill Categories

To classify skills within Gentile's taxonomy, the four environmental demand conditions (stationary and in-motion regulatory conditions, the absence or presence of intertrial variability) are crossed with the four possible action requirements (body stability or transport, the absence or presence of object manipulation) to yield 16 skill categories. Table 2.2 illustrates the taxonomy along with examples of two skills in each of the 16 categories.

Each of the 16 categories into which skills can be classified imposes a different set of demands on performers. Gentile specified that as the number and complexity of environmental and task demands to which a performer must attend and control increases, the difficulty of task performance also increases (Gentile, 2000). In the taxonomy, environmental demands increase with movement down the categorical columns, whereas action requirements increase with movement from left to right across the categorical rows. Skills in the upper left-hand category represent the simplest and least difficult skills to perform, whereas those skills in the bottom right-hand category are the most complex and demanding. For ease of reference, categories are labeled by number from 1 to 4 down columns, and by letter from A to D across rows, with an increase in either direction indicating greater skill complexity. As skills move diagonally across the columns from left to right, and down the rows from top to bottom, performance demands increase, with skills in category 1A being the simplest, and those in category 4D the most complex.

Application of Gentile's Taxonomy

Because the categorical classification of skills in Gentile's taxonomy progressively increases in task difficulty with movement across columns and down rows, the taxonomy can be used to assess and compare different skills, or variations of the same skill, in regard to demands placed upon performers. This makes possible two important applications of the taxonomy. First, as Gentile originally intended when developing the taxonomy, it can be used to evaluate an individual's level of movement proficiency. As a diagnostic tool in physical therapy settings, the taxonomy provides an effective method for gauging a patient's movement capabilities and limitations (Huxham, Goldie, and Patla, 2001). For example, a therapist could evaluate a patient recovering from hip

TABLE **2.2**
Gentile's Taxonomy

			Action Requirements			
			Body Stability		Body Transport	
			No Objection Manipulation	Object Manipulation	No Objection Manipulation	Object Manipulation
Environmental Demands	Stationary Regulatory Conditions	No Intertrial Variability	1A Standing on a flat surface with arms held out to your sides Doing sit-ups on a flat surface	1B Playing the piano Practicing basket-ball free throws	1C Walking up a flight of stairs Practicing the same balance bar routine	1D Using crutches to walk down an empty hallway Throwing a javelin
		Intertrial Variability	2A Practicing the movements of various golf swings without using a golf club Using sign language	2B Cutting vegetables with a knife on a cutting board Polishing silverware	2C Competing in the high jump Carrying a plate of food from your kitchen to the dining room	2D Raking leaves in a yard Participating in a sack race
	In-Motion Regulatory Conditions	No Intertrial Variability	3A Standing on a moving escalator Timing your swing at baseballs pitched by a machine without using a bat	3B Standing on a moving escalator while drinking a cup of coffee Doing tricks with a yo-yo	3C Walking on a moving escalator Practicing a dance routine that must be timed with a partner with whom you have no contact	3D A game of bowling (first ball in each frame) Dribbling a soccer ball with no defenders
		Intertrial Variability	4A Standing in a moving bus Riding a horse on a country lane	4B Balancing a spinning basketball on the tips of your fingers Catching balls pitched to home plate	4C Playfully chasing a pet dog Swimming in a moving river	4D A game of bowling (all balls including spares) Surfing

replacement surgery by first assessing the patient's ability to stand on a flat surface and maintain balance while extending his or her arms in various directions (category 1A in the taxonomy). If the patient demonstrated sufficient confidence and capability performing these actions, the same activity could be tested with the patient holding and moving a beanbag from hand to hand (category 1B). Progressively, the patient could be asked to walk a short distance with hands free (category 1C), and then while carrying a beanbag in both hands (category 1D). If the patient were able to perform all of these actions successfully, the therapist could then repeat the same sequence but vary the intertrial regulatory conditions by having the patient attempt each skill progression on a flat unencumbered surface, a carpeted surface, and a flat surface where movement around a chair or other obstacle was required (progression in this sequence would be from 2A to 2D). By gradually varying task demands, the therapist can accurately evaluate a patient's level of movement proficiency, prescribe appropriate training activities for the patient's current level of movement capabilities, and meaningfully measure progress over the course of treatment.

In the example just cited, an important feature of the evaluation sequence can be observed. That is, beyond simply evaluating an individual's current movement capabilities, the taxonomy effectively charts a progression of increasingly challenging activities. This leads to a second major use of the taxonomy, which is the identification of systematically more demanding skill variations. In our example, if the patient was capable of standing on a flat surface while manipulating beanbags but was not able to maintain stability when attempting to walk, the taxonomy could be used by the therapist to effectively plan a progressive sequence of treatment activities. Because the patient starts at category 1B in the taxonomy, the most immediate goal of treatment would be to emphasize walking on a flat surface while remaining unencumbered by any demands for manipulating objects (category 1C). Progressively, as the patient could successfully meet the challenges of each new category, the therapist would devise activities representing the next category in order to continually, in gradual steps, increase the patient's movement capabilities.

The use of Gentile's taxonomy to plan meaningful instructional progressions in a variety of skills and performance settings has provided an effective

BOX 2.7 Using Gentile's Taxonomy

Gentile's taxonomy provides an effective guide for systematically identifying meaningful skill progressions. Can you identify meaningful steps when teaching someone a new skill using the taxonomy? Try developing a description of progressive activities a person might practice to acquire one of the following skills. Begin with category 1A and describe practice activities for each category to 16D.

- Returning a serve in tennis
- Skiing a downhill slalom course
- Regaining the capability to ride a bicycle after spinal surgery
- Dribbling a soccer ball against defenders
- Learning a ballroom dance routine

tool for movement practitioners when planning instructional activities. When used in physical education settings, the taxonomy provides a coherent framework for curricular development (Adams, 1999). The teacher instructing a unit of softball, for example, may observe that a particular class of students is having difficulty learning to bat when thrown pitched balls. In this case, the instructor may decide students are not ready for the demands imposed by live pitches (i.e., both regulatory and intertrial variability) and could reduce these challenges to manageable levels by stabilizing environmental conditions. To do this, the teacher could have students learn correct movement patterns by hitting the softball from a batting tee set at an appropriate midbody level while maintaining both feet in place (category 1B). Progressions could then be planned to practice hitting movements without a bat but by moving the front foot toward the tee and "stepping into the pitch" (category 1C); by adding the bat and hitting the ball while stepping forward (category 1D); and then by repeating the same activities while varying the height of the tee on which the ball is placed (categories 2A to 2D). Once skill proficiency in these categories was attained, the progressions would be repeated with a pitcher throwing the same type of pitch on each trial (categories 3A to 3D) and finally with the pitcher throwing a variety of different pitches (categories 4A to 4D). The systematic and incremental increase in task demands made possible by using Gentile's taxonomy provides the instructor with a useful tool for meaningfully planning an effective series of progressively challenging, yet manageable, steps in meeting skill goals. It can also be noted that instructors may decide to begin progressions within any category of the taxonomy, depending upon an evaluation of student capabilities and readiness (progressions need not always begin with category 1A), and also that some categorical steps may be omitted depending on learner needs and progress.

SUMMARY

Skills of many and varied types make up a majority of the activities comprising daily life. Depending upon the requisite capabilities most critical in accomplishing their goals, skills are classified into cognitive, perceptual, and motor domains.

Motor skills, as a separate domain of skill, are defined in two ways:

- The classic definition of motor skills assumes a task perspective and defines motor skills as voluntary, goal-directed, learned behaviors accomplished primarily through contributions of the muscular-skeletal system.
- Guthrie's definition of motor skills assumes a performance perspective and defines motor skills as maximizing goal attainment while minimizing energy expenditures and movement time.

The study of motor skills comprises three components influencing performance, each of which plays a role in both facilitating and limiting performance capabilities:

- Environment
- Task
- Person

Four aspects of skilled behavior characterize all motor skills:

- Motor equivalence
- Motor variability
- Motor consistency
- Motor modifiability

Among the most persistent problems facing motor skill researchers, four in particular underscore differences in theoretical perspectives and are the most challenging to researchers:

- The degrees of freedom problem
- The perceptual-motor integration problem
- The serial-order problem
- The skill acquisition problem

Two systems for classifying motor skills are used today:

- One-dimensional classification systems assume a task perspective and classify skills along a continuum. One-dimensional systems have been developed based upon the stability environmental features (closed vs. open), temporal predictability (discrete, serial, and continuous), and movement precision (fine vs. gross).
- Gentile's two-dimensional system classifies skills into 16 categories representing combinations of environmental demands and action requirements. The taxonomy is particularly useful for purposes of evaluating movement capabilities and planning instruction progressions when teaching motor skills.

LEARNING EXERCISES

1. Observe a venue where people are performing various motor skills (it could be a sporting event, a work situation, a clinical setting, or even some public display where people are involved in different movement activities). Observe and describe the situation and the kinds of movement activities taking place. Look for examples of each of the seven one-dimensional categories of skill and specifically describe one example of each of these seven categories.
2. Keep a log of your movement activities for one day, recording specific examples of each of the four skill characteristics identified by Sheridan (you will obviously not record every motor skill you perform). From your log, provide several examples of each of the four skill characteristics. Does any one type of skill characteristic appear to be more prevalent than others? What insights about your daily motor skill activities did you gain from your observations?
3. Select an example of a complex motor skill with which you are well acquainted (sports or recreational skill, occupational skill, daily life skill, etc.). For this skill, design an instructional progression based upon Gentile's taxonomy that could be used to instruct someone who was unpracticed or incapacitated relative to the skill; begin your progression at the simplest performance level and advance