MOTOR LEARNING AND CONTROL

Concepts and Applications

Richard Magill
David Anderson

Eleventh Edition

Mc Graw Hill Education

ELEVENTH EDITION

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Concepts and Applications

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Preface

This eleventh edition primarily updates the previous edition by adding more recent research and interpretations of the concepts and theoretical views associated with those concepts that were in the tenth edition. An important feature of this new edition is that it continues its two most distinctive features as an introductory motor learning and control textbook: its overall approach to the study of motor learning and control and the organization of the implementation of that approach. In every edition of this book, the overall approach has been the presentation of motor learning and control "concepts" to identify the common theme of each chapter. The concepts should be viewed as generalized statements and conclusions synthesized from collections of research findings. Following the concept statement is a description of a real-world application of the concept, which is then followed by discussions of specific topics and issues associated with the concept. An important part of these discussions are summaries of research evidence, on which we base our present knowledge of each topic and issue, as well as the implications of this knowledge for practitioners. The benefit of this organizational scheme is the presentation of motor learning and control as a set of principles and guidelines for practitioners, which are based on research evidence rather than on tradition or "how things have always been done."

Our goal for this edition continues to be to provide an introductory study of motor learning and control for students who aspire to become practitioners in various professions. As in previous editions, the achievement of this goal involves the inclusion of research examples that demonstrate the evidence-based foundation for the motor learning and control concepts. It is important to note that the research examples are just that—examples; the intent of the discussion of research about a specific topic, therefore, is not to present an extensive review of the research literature or to investigate the various controversial views that may exist on a topic.

NEW TO THIS EDITION

New Research

Because an important goal of this book is to provide research evidence to support the various concepts and applications, it is essential to regularly update the research to maintain the book's relevance. As in previous editions, each chapter of the eleventh edition includes updated research in the text, the *A Closer Look* boxes, and in the *Related Readings* sections. Research related to motor learning and control continues to increase, as evidenced by the ever-expanding amount of research articles and chapters published each year. Because of the availability of this new information, it is essential that an introductory textbook provide the most up-to-date evidence available to support the numerous concepts and applications that can be derived from this research. But, the caveat here is to not overwhelm the reader with a litany of research studies.

It is with this point in mind that we have as a primary intent to present examples of research studies that provide empirical support for the concepts discussed rather than to provide exhaustive reviews of the available research.

NEW OR EXPANDED TOPICS IN SPECIFIC CHAPTERS

Chapter 1: The Classification of Motor Skills

- Added a new example to clarify the many-to-one and one-to-many relationship between movements and neuromotor processes
- Clarified the section on why it is important to distinguish actions, movements, and neuromotor processes
- Added text to clarify the notion of regulatory conditions
- Simplified the text that describes the practical applications of Gentile's taxonomy

Chapter 2: The Measurement of Motor Performance

- Updated the definitions of performance outcome measures and performance production measures
- Clarified the description of the kinematic measure "velocity"
- Updated the reference to Susan Hall's textbook of biomechanics
- Clarified the description of "relative phase"
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 3: Motor Abilities

- Updated and added new research relevant to the concept discussed in the chapter

Chapter 4: Neuromotor Basis for Motor Control

- Added a mnemonic to help remember the distinction between motor and sensory neurons
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 5: Motor Control Theories

- Updated and added new research relevant to the concept discussed in the chapter

Chapter 6: Sensory Components of Motor Control

- Updated the role of the vestibular system in motor control
- Added an example of how tactile feedback influences movement timing
- Clarified the temporal occlusion procedure used to evaluate the role of vision in motor control
- Clarified text related to the two visual systems for motor control
- Clarified how the optical variable Tau triggers an action
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 7: Performance and Motor Control Characteristics of Functional Skills

- Added text about the role of vision in prehension
- Clarified how the optical variable Tau is used during catching
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 8: Action Preparation

- Added another example of how the end-state-comfort effect influences movement preparation
- Elaborated on how elite performers use preperformance routines
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 9: Attention as a Limited Capacity Resource

- Updated the Closer Look box on how cell phone use influences driving

- Updated differences between skilled and less-skilled soccer players in their use of visual search strategies
- Updated the range of skills in which the "quiet eye" has been demonstrated
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 10: Memory Components, Forgetting, and Strategies

- Updated and added new research relevant to the concept discussed in the chapter

Chapter 11: Defining and Assessing Learning

- Expanded and clarified discussion of the meaning of "persistence" as a general performance characteristic of skill learning
- Added a specific research example to illustrate how performance during practice can overestimate the amount of learning that occurred during practice of a motor skill
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 12: The Stages of Learning

- Added footnote to identify research articles that provide more elaborate discussions about the relationship between coordination changes and motor control during motor skill acquisition
- Added a specific reference in text for a meta-analysis of research related to results of brain imaging showing differences in brain regions active during early and later stages of learning
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 13: Transfer of Learning

- Added new real-world example of spatial location change that results in negative transfer
- Expanded example of rehabilitation therapy situation that would induce negative transfer
- Related the cognitive explanation for bilateral transfer to the first stage of learning as described in chapter 12
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 14: Demonstration and Verbal Instructions

- Added reference to identify a meta-analysis of 64 studies that showed evidence for the conclusion that demonstrations convey relative motion information
- Added footnote to identify a review of research supporting mirror neurons
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 15: Augmented Feedback

- Added clinical example of use of erroneous augmented feedback
- Expanded discussion of why beginners ask for KR after good trials during practice
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 16: Practice Variability and Specificity

- Elaborated on discussion of Shea and Kohl experiment to clarify the procedures with respect to the task the participants learned
- Clarified the relationship between different types of practice schedules and the amount of contextual interference associated with each
- Expanded the discussion of the "challenge point hypothesis" to more directly relate it to the generalization limits of the contextual interference effect
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 17: The Amount and Distribution of Practice

- Added in Application section the relationship between amount of practice and frequency of augmented feedback discussed in chapter 15

- Elaborated on meaning of phrase "diminishing returns" as it relates to amount of overlearning and amount of actual learning
- Elaborated on discussion of meaning of terms "massed" and "distributed" practice
- Updated and added references to research published since previous edition

Chapter 18: Whole and Part Practice

- Elaborated on the skill complexity—organization relationship for making the whole-part practice decision
- Expanded the "A Closer Look" box discussion of how to apply the whole-part practice decision to three-ball cascade juggling
- Added a dance instruction example to the "reducing speed" strategy for implementing the simplification method for learning complex skills
- Updated and added new research relevant to the concept discussed in the chapter

Chapter 19: Mental Practice

- Related mental practice as an action preparation strategy to the discussion in chapter 8
- Added specific reference for reading a review of research on the use of motor imagery for upper limb rehabilitation
- Updated and added new research relevant to the concept discussed in the chapter

SUCCESSFUL FEATURES

Motor Learning and Control: Concepts and Applications continues to offer the following features from the previous editions that have helped enhance student learning.

Concepts
Each chapter begins with a concept statement to present a principle or conclusion that describes the focus of the chapter. The goal of these statements is to provide students with a guide for understanding the chapter content, which provides the various pieces of information that led to the concept statement.

Application
Following the concept statement, the application section describes in practical terms the relevance of the chapter concept and content to everyday experiences and professional practice.

Application Problem to Solve
This feature, which follows the application section at the beginning of each chapter, presents a specific application problem for students to work on as they engage in reading the discussion section of the chapter.

Discussion
This section presents the specific information from which the concept statement was derived. It includes the key topics and issues relevant to the chapter concept along with summaries and examples of research that provide evidence to support the various points presented in the chapter.

A Closer Look Boxes
Each chapter contains several boxes. The title for each box indicates its content. These boxes typically serve one of several purposes: to provide more detail about a research study than is provided in the text; to describe a situation that applies a point in the discussion to a professional practice situation; or to describe a relevant issue that allows the student to explore a topic beyond the limits of the text.

Summary
Each chapter concludes with a summary that presents the main ideas addressed in the discussion section. Using this tool, the student can return easily to a topic in the chapter for clarification or study.

Points for the Practitioner
This feature describes how the chapter topic relates to the practice or performance setting. It encourages students to think about how they will use this information in practical ways.

Related Readings
For students who want to know more about a particular topic, this list at the end of each chapter offers carefully selected research journal articles, books, and book chapters for further exploration.

Study Questions
A set of questions appears at the end of each chapter to encourage students to review and analyze the chapter content.

Specific Application Problem as a Study Question
The final study question presents an application problem to solve as a culminating experience for the student to use the information presented in the chapter. This problem differs from the one located at the beginning of the chapter by describing a situation students might experience in their future professional experience.

Definition Boxes
Key terms, which are highlighted in the text in boldface type, are defined in corresponding boxes for easy reference. Other important terms in the text appear in italics for emphasis.

Lab Links
The previous four editions included, as part of McGraw-Hill's Online Learning Center for this book, a laboratory manual of laboratory experiences for most chapters. These experiences are available for this edition as well. In the eleventh edition, these laboratory experiences are identified by "Lab Links" boxes in the margins.

Glossary
At the end of the book, all the key terms defined in the definition boxes are included in a comprehensive glossary. This glossary is useful as a quick reference and a helpful review to prepare for examinations.

Name Index
In addition to the regular subject index, this book features a name index, which identifies and locates all the names referred to in the book. Included in this list are the names of important people who have been or are leaders in the field of motor learning and control.

DIGITAL RESOURCES

The eleventh edition of *Motor Learning and Control* is now available online with Connect, McGraw-Hill Education's integrated assignment and assessment platform. Connect also offers SmartBook for the new edition, which is the first adaptive reading experience proven to improve grades and help students study more effectively. All of the title's website content is also available on Connect, including access to the full course Instructor's Manual, Test Bank, and PowerPoint slides, and Student Lab Manual.

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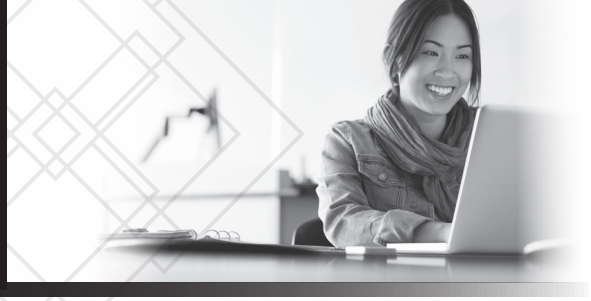

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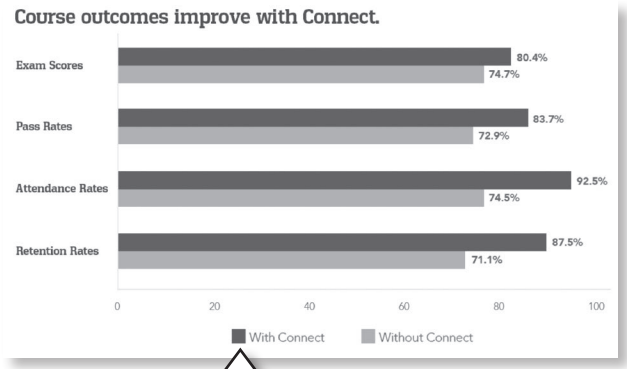

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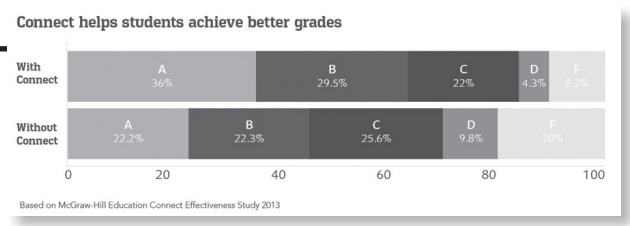

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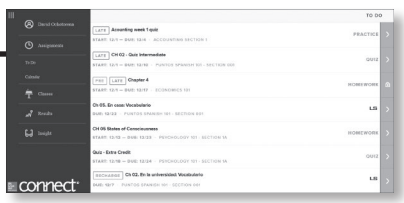

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The creation of a new edition of a textbook requires the support of colleagues, friends, and loved ones. Each of us wants to identify specific sources of support, without which we could not have completed this eleventh edition.

Richard wants to acknowledge students and colleagues throughout the world who have told or sent him their ideas and suggestions concerning ways to make the book work better for them in the classes they teach. He greatly appreciates their interest in assisting his efforts to develop this new edition. On a more personal level, he again acknowledges and thanks his wife, Susan Koff, for her support, encouragement, suggestions, and patience. He is dedicating this edition to her for her constancy in "being there."

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Richard A. Magill
New York City, New York

David I. Anderson
San Francisco, California

From Richard:

To my wife

Susan R. Koff

From David:

To my father

Ian Hugh Anderson

Introduction to Motor Skills and Abilities

UNIT **ONE**

CHAPTER 1
The Classification of Motor Skills

CHAPTER 2
The Measurement of Motor Performance

CHAPTER 3
Motor Abilities

CHAPTER 1

The Classification of Motor Skills

Concept: Classifying skills into general categories helps us to understand the demands those skills place on the performer/learner.

After completing this chapter, you will be able to

- Define and distinguish the terms *actions, movements, and neuromotor processes,* and give examples of each
- Describe the one common motor skill characteristic for each of three motor skill classification systems, the two categories of skills in each system, and examples of motor skills in each category of each system
- Describe the two dimensions used to classify skills in the Gentile taxonomy of motor skills and the classification characteristic included within each dimension
- Discuss ways to use the Gentile taxonomy of motor skills in physical rehabilitation or physical education and sport contexts

APPLICATION

We are born to move, but *learn* to move skillfully. When people run, walk with an artificial limb, throw a baseball, hit a tennis ball, play the piano, dance, or operate a wood lathe, they are engaged in the performance of a type of human behavior called *motor skills.* Every motor skill in our repertoire is the product of a long and often arduous process of acquisition. We delight in watching young children acquire the basic skills of sitting, standing, walking, reaching, and grasping that permit ever-increasing control over the environment. We're enthralled by the elite athlete and the professional musician and dancer who perform feats of movement control that defy the imagination. We're equally impressed by the surgeon and bomb disposal technician who can maintain a steady hand and dexterous coordination under the most intense pressure. Sometimes we even marvel at our own ability to find new and better ways to perform activities of daily living, and when we stop to think, we're often surprised by just how efficiently we're able to perform tasks that once seemed impossible to master. On the other hand, we lament the loss of coordination and control that follow injury, disease, and disability. Such losses help us to realize just how important skill is to our sense of control over the world around us.

These simple observations highlight how dependent we are on our capacity to learn and perform motor skills. Skill, when viewed broadly as a capacity to control our bodies and the world around us, is a biological necessity. The degree of skill we possess is expressed through our ability to use movements to deal with the myriad problems we encounter on a daily basis. Without some degree of skill to escape from predators, to find food, to find or build shelter, and to procreate, animals would quickly perish. Humans are unrivaled in their capacity for acquiring skill, as witnessed by the incredible feats of the professional athlete, dancer, and musician, but also the young child who can ride a bicycle or the patient relearning to walk after an accident. We are capable of a degree of resourcefulness and adaptability that

far exceeds the capabilities of other animals. These traits have propelled humans to the top of the food chain and allowed us to profoundly change the environment in which we live.

This book examines our fascinating capacity to control and acquire motor skills. The book focuses on helping you understand how people perform and learn, and how you can help people perform and learn, motor skills. It highlights a wide range of factors that are known to influence how motor skills are performed, how quickly they are learned, how well they are learned, and how well they are retained over long periods of time. In addition to the traditional factors that have been emphasized in the field, such as the way in which instruction and augmented feedback are provided, and the amount and type of practice given to the learner, the book also covers a range of other variables that have become prominent in the last few years, including the learner's motivation and self-confidence, as well as his or her control over what happens during practice.

As you engage in this study, you will find it useful to draw general conclusions to apply what you learn to a broad range of motor skills, rather than making many specific statements about many skills. The starting point for doing this is the classification of motor skills into broad categories that emphasize the similarities rather than the differences among skills.

For example, the skill of maneuvering a wheelchair through a crowded hallway and that of hitting a pitched baseball seem quite distinct. However, both skills have one characteristic in common that influences how they are learned and performed. People must perform both skills in an "open" environment. This means that to perform the skill successfully, a person must adapt certain aspects of his or her movements to changing characteristics in the performance environment. For the wheelchair skill, this means that the person must be able to maneuver successfully through a crowded hallway in which people are walking in various directions and speeds. For hitting a baseball, the changing environment involves the ball itself as it moves toward the person. For both of these skills, performance success requires the performer to adapt quickly and accurately to changing conditions. When we view them in terms of this common characteristic, we can see that these two seemingly diverse skills are related.

Application Problem to Solve Identify five motor skills that you can perform, either those that you do routinely or those you do for recreation, fitness, or sports, and classify each into one of the categories in each of the motor skill classification systems you will study in this chapter; indicate why each skill would be classified this way.

DISCUSSION

To begin our study of motor learning and motor control, we will describe how researchers and professionals use these two terms to delineate areas of research and professional application. Both areas of study share a focus on the performance of **motor skills,** which we define as *activities or tasks that require voluntary control over movements of the joints and body segments to achieve a goal.* Researchers study motor skills in many ways. Two are especially relevant to discussions in this book: *motor learning* and *motor control;* a third (known as *motor development*) is commonly related to these two areas of study, but it is not a focus of this book.

The study of **motor learning** emphasizes the acquisition of motor skills, the performance enhancement of learned or highly experienced motor skills, or the

motor skills activities or tasks that require voluntary control over movements of the joints and body segments to achieve a goal.

motor learning the acquisition of motor skills, the performance enhancement of learned or highly experienced motor skills, or the reacquisition of skills that are difficult to perform or cannot be performed because of injury, disease, and the like. Of interest are the behavioral and/or neurological changes that occur as a person learns a motor skill and the variables that influence those changes.

reacquisition of skills that are difficult to perform or cannot be performed because of injury, disease, and the like. Of interest are the *behavioral and/or neurological changes* that occur as a person learns a motor skill and the variables that influence those changes. An example of a question that a motor learning researcher would seek to answer is, Does the type of feedback an instructor gives to a person learning (or relearning) a motor skill influence how quickly and how well the skill will be learned?

In the study of **motor control,** the question of interest is how our neuromuscular system functions to activate and coordinate the muscles and limbs involved in the performance of a motor skill. Researchers may investigate this question while a person is learning a new skill or performing a well-learned or highly experienced skill. An example of a question that a motor control researcher would seek to answer is, Are the movements of the arms and legs coordinated in similar or distinct ways when a person walks or runs at various speeds?

A related area is the study of **motor development,** which concerns issues related to either or both motor learning and control, but is primarily interested in the relationship between these issues and human development from infancy to old age. Those who study motor development place much greater emphasis on how processes such as growth and maturation influence changes in motor behavior. An example of a question that a motor development researcher would seek to answer is, How do the elderly compare with young adults in terms of how quickly they can decide what they need to do to avoid a collision with another person while walking in a crowded hallway?

In their investigations researchers in these areas of study assume that motor skill performance is influenced by the (1) motor skill, (2) performance environment, and (3) physical and psychological characteristics of the person performing the skill (see figure 1.1). Researchers use this assumption to investigate questions about learning, control, and development from *behavioral and/or neurophysiological levels of study.*[1] At the *behavioral level*, researchers investigate questions by observing and analyzing human behavior as it is affected by characteristics of any or a combination of these influences. Researchers may observe people performing motor skills in laboratory, clinical, or natural settings. To answer the research questions described in the preceding paragraphs, researchers could engage in either the behavioral or neurophysiological level of study. As you will read in chapter 2, researchers, as well as practitioners, use a variety of performance measures to quantitatively or qualitatively evaluate a person's performance of a skill. Researchers who study motor learning, control, and development will often use their observations of behavior (i.e., motor skill performance) to infer neurophysiological mechanisms that are responsible for the behavior. For investigations at a neurophysiological level of study, researchers directly or indirectly observe central and peripheral nervous system components as they interact with muscles involved in performing a motor skill.

The focus of this textbook is on motor learning and control without reference to developmental concerns, although developmental relevance is considered in several instances. Also, while you will be introduced to some neurophysiological aspects of motor learning and control, a behavioral level of study dominates the textbook's approach. In addition, you will see evidence for and examples of how the three influences on motor skill performance, as described in the previous paragraph, form the basis for our understanding of the learning and control of motor skills.

To establish a foundation on which to build your study of motor learning and control, it is essential to have a good understanding of motor skills, which are the focus of both areas of study and are an important component of the three general influences on motor skill performance depicted in figure 1.1. To help you develop your understanding of motor skills, the remainder of this chapter will address two important points. First, we will consider what distinguishes motor skills from other skills and define some other commonly used terms related to the term *motor skill.* Second, we will discuss four different approaches to classifying motor skills into categories that identify common characteristics of various skills.

[1]You will sometimes see the term *level of analysis* rather than *level of study.* We will consider these phrases to be synonymous and interchangeable.

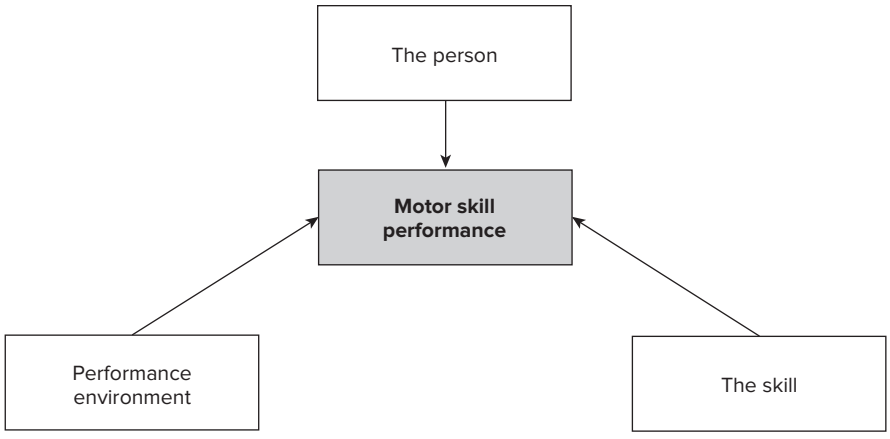

FIGURE 1.1 Three influences on how we perform a motor skill. To understand the learning and control of motor skills, it is important to recognize that the performance of any motor skill is influenced by characteristics of the skill itself, the person performing the skill, and the environment in which the skill is performed.

The benefit of classifying skills is that it can provide you with an appropriate basis for establishing generalizations, or principles, about how we perform and learn motor skills. These generalizations will enable you in turn to understand theories about skill performance and learning. Additionally, they help establish guidelines for instructors, coaches, and therapists who must develop effective strategies that will enhance motor skill learning and rehabilitation.

SKILLS, ACTIONS, MOVEMENTS, AND NEUROMOTOR PROCESSES

Several terms in the motor learning and control literature are related to the term *motor skills.* These are *skills, actions, movements,* and *neuromotor processes.* Each term is used in a specific way you should understand and use correctly.

What Is Skill?

Before differentiating the terms *skills, actions, movements,* and *neuromotor processes* from each other, it is important to differentiate the two ways in which the term **skill** is used. First, *skill* is a commonly used word that in this text denotes an activity or *task that has a specific purpose or goal to achieve.* We will elaborate on this usage of the term in the next section of the chapter. Second, the term *skill* is used to denote some degree of competence or capacity to perform a task. For example, we might refer to someone as a skilled *golfer*, or a *skilled* neurosurgeon, or a *skilled* pianist. When the term is used in this way, we place a value judgment on the quality of someone's performance. We classify their performance somewhere along a continuum that varies from unskilled to highly skilled.

motor control how our neuromuscular system functions to activate and coordinate the muscles and limbs involved in the performance of a motor skill. Researchers may investigate this question while a person is learning a new skill or performing a well-learned or highly experienced skill.

motor development human development from infancy to old age with specific interest in issues related to either motor learning or motor control.

skill (a) an activity or task that has a specific purpose or goal to achieve; (b) an indicator of quality of performance.

Although the second usage of the term *skill* has been defined in many different ways, three criteria are typically analyzed to determine where along the skill continuum a person's performance would be classified. The first criterion is the extent to which the person can consistently achieve the goal of the task, with highly skilled individuals showing a greater capacity to consistently achieve the goal of the task than less-skilled participants. The second criterion is the extent to which the person can achieve the task under a range of different conditions. Highly skilled individuals can achieve success under a much wider range of conditions and circumstances than their less-skilled counterparts. For example, the skilled quarterback can complete passes to many different receivers running many different routes at many different speeds. He can complete the passes on different fields, in different weather conditions, when fatigued or injured, and when faced with many different types of pressure from his opponents or from the consequences associated with not performing up to expectation. The highly skilled individual typically has a much richer repertoire of movements to draw upon when faced with the myriad of situations he or she is likely to encounter.

The final criterion used to assess individuals' level of skill is their degree of efficiency. Skilled individuals are much more efficient than less-skilled individuals. Their efficiency can be seen in the strategies they use to solve problems, in the way they pick up and process information and deploy their attention, and in the amount of muscular effort they use to accomplish a task. Skilled individuals often make difficult tasks look effortless and they can appear to have all the time in the world, even in tasks that impose severe time limitations on the performer.

As students of motor learning and control, understanding the characteristics of skill and how we become skillful is a central concern. One might say that it is *the* central concern. Throughout the book you will see many references to the characteristics of skill and we will pay particular attention to the process of becoming skillful in chapter 12 and to the variety of ways in which skill acquisition can be facilitated in chapters 13 to 19.

Skills and Actions

As noted above, the term *skill* is also used to denote an activity or *task that has a specific purpose or goal to achieve.* For example, we commonly say that "multiplication is a fundamental skill of mathematics" or "playing the piano is a skill that takes practice." Of these two examples, the skill of piano playing includes a *motor skill* because it requires voluntary limb movement to achieve its goal, which is to produce music. Looked at this way, the skill of piano playing involves the goal of striking the correct keys in the proper sequence and at the appropriate time, and it requires control over posture and finger and hand movement to achieve that goal. The purpose of a motor skill is to cause some type of change in the environment or in the person's relation to the environment. The purpose describes the specific problem for the mover to solve. Sometimes, many different movements are required to solve the problem.

It is important to point out that multiplication, which was used in the previous paragraph as an example of a skill, is commonly referred to as a *cognitive skill.* This means that the skill requires cognitive (i.e., mental) activity, which includes decision making, problem solving, remembering, and the like. It differs from a motor skill in that it does *not* require voluntary limb movement to achieve its goal. Although a person could use a motor skill such as handwriting or pressing the keys on a calculator or computer to carry out the multiplication task, movement activities such as these are not required. In contrast, the skill of piano playing involves cognitive activities, but requires hand and finger movements.

In the motor learning and control research literature, a term that has become increasingly common is **actions.** For our purposes, we will use this term synonymously and interchangeably with the term *motor skills.*

Characteristics of skills and actions. Several characteristics are common to motor skills. First, there is *a goal to achieve.* This means that motor skills have a purpose. Sometimes you will see the term *action goal* used to refer to the goal of a motor skill. Second, the types of motor skills of interest in

this text are *performed voluntarily;* in other words, we are not considering reflexes as skills. Although an eye blink may have a purpose and involve movement, it occurs involuntarily and is therefore not a skill in the sense in which we are using the term. Third, a motor skill *requires movement of joints and body segments* to accomplish the goal of the task. This characteristic is especially important because it is the basis for distinguishing motor skills from other types of human skills.

One additional characteristic identifies the types of motor skills of interest in this text: They *need to be learned, or relearned,* in order for a person to achieve the goal of the skill. In our example, piano playing clearly must be learned. But consider a skill like walking. Although walking may seem to be something that humans do "naturally," it must be learned by the infant who is attempting to move in his or her environment by this new and exciting means of locomotion. And walking is a skill some people may need to relearn. Examples are people who have had strokes, or hip or knee joint replacements, as well as people who must learn to walk with artificial legs.

Movements

In the motor learning and control research literature, the term **movements** indicates *specific patterns of motion among joints and body segments.* This means that movements are the component parts of motor skills. In other words, movements are the means by which action goals are accomplished or problems are solved. For example, locomotion is an action that has the goal of transporting the body from one location to another. The action goal could be accomplished using many different movement patterns, including walking, running, hopping, skipping, galloping, and so on. Each movement pattern is defined by a particular pattern of relative motions among joints and body segments, though each would be an effective way of solving the problem of transporting the body from one location to another. In addition, assuming a person chooses walking as the means to locomote from one place to another, a variety of head, body, and limb motions can occur that enable a person to walk successfully. For example, our arms and legs move in different and distinct ways when we walk on a concrete sidewalk and when we walk on an icy sidewalk—or on a sandy beach. However, although certain motions may differ, the motor skill we perform in each of these different situations is walking.

The important point here is that a variety of movements can accomplish the same action goal. This highlights the *many-to-one* relationship between movements and actions. For example, if a person's goal when walking up a set of stairs is to get to the top of the stairs, he or she can achieve this goal by using a variety of different movements. A person can take one step at a time very slowly, or take each step very quickly, or take two steps at a time, and so on. In each situation, the action goal is the same but the movements the person uses to achieve the goal are different. Similarly, if a person's action goal is to throw a ball so that it hits a target—which might be a person who would catch it—the goal can be achieved with several different movement characteristics. For example, the person could throw the ball overhand, sidearm, or underhand. All would achieve the action goal but would use very different movement characteristics.

The relationship between movements and actions is also *one-to-many,* meaning that one movement pattern could be used to achieve many different action goals. For example, walking or swimming could be used to move the body from one location to another, but they could also be used to maintain the body in one location if walking on a treadmill or swimming against a current. So, when the context changes, the same movement can be used to accomplish completely different purposes. Movie aficionados may remember the classic scene from the movie *The Karate Kid* in which Mr. Miyagi asks Daniel to wash and then polish his car using wax-on-wax-off movements with his hands. This is another example of the one-to-many relationship between movements and actions. In one context,

actions see *motor skills.*

movements specific patterns of motion among joints and body segments used to accomplish action goals.

A CLOSER LOOK

Examples of Skills/Actions, Goals, and Movements

The following examples illustrate how a skill or action can have various goals, which would require movements that differ according to the action goal. For each of the goals within a skill/action, consider different movements that could be used to allow a person to achieve the goal while carrying out the same skill/action.

Skills/Actions	Goal
1. Locomotion	a. To move from the front of an empty room to the back of the room
	b. To move from one store to another store in a crowded mall
	c. To move on a treadmill
2. Throwing	a. To accurately throw a small round ball at a target on the wall
	b. To throw a small round ball as far as possible
	c. To throw a beach ball to a friend to catch
3. Reaching and grasping an object	a. To pick up a full coffee mug from a table and drink from it
	b. To pick up a bowl of soup to move it from one location on a table to another location on the table
	c. To pick up a can of juice and shake it
4. Sit to stand	a. To stand up from sitting in a wheelchair
	b. To stand up from sitting on a seat in a bus
	c. To stand up from sitting on the side of a bed

the wax-on-wax-off movements could be used to polish a car and in another context they could be used to protect the person against an attacker. The take-home message here is that the purpose any movement fulfills is entirely determined by the context in which the movement occurs.

Neuromotor Processes

Neuromotor processes represent the third level on which motor behavior is often analyzed. In contrast to actions and movements, which can be clearly seen by the naked eye, neuromotor processes are the mechanisms within the central and peripheral nervous system as well as the muscular system that underlie the control of movements and actions. These processes cannot be observed directly with the naked eye, though they can be measured quite precisely using a number of different techniques that are introduced in chapter 2. The relationship between neuromotor processes and movements is also many-to-one and one-to-many. For example, many combinations of muscle fibers could be used to lift the arm above the head. This capacity of the neuromuscular system enables the arm motion to be reproduced consistently even though some muscle fibers might not contribute to the movement because they become fatigued or injured. On the other hand, highlighting the one-to-many relationship between neuromotor processes and movements, a muscle might be activated in an identical way from one moment to the next but lead to a different movement if the context changes. The function of the pectoralis major muscle provides a good example here. When the arm is held out to the side below the horizontal, activation of the pectoralis major muscle brings the arm back to the side (it adducts the arm). However, when the arm is above the horizontal, the same activation of the pectoralis muscle will bring the arm closer to the head (it abducts it). The resulting movement is completely dependent on the initial position of the arm even though the muscle is activated in exactly the same way. Similarly, the same activation of the biceps brachii might flex the elbow in one situation but lead to no movement or elbow extension when a weight is held in the hand. Again, the resulting

movement is dependent on the context in which the neuromotor processes are activated.

Why Distinguish Actions, Movements, and Neuromotor Processes

There are three reasons why it is important and useful to distinguish these three levels of study. First, actions (skills), movements, and neuromotor processes represent the order in which motor control and learning are prioritized, thus highlighting what should be emphasized at different stages of learning. The learner's first priority is to understand the action goal and to explore strategies to achieve it. The second priority is to discover the best movement to accomplish the action goal given the unique characteristics of the learner and environmental context. The third priority is to refine the movement and make it more efficient by modifying neuromotor processes. Too often, practitioners ignore this hierarchy of priorities and introduce skills as movement patterns to be learned rather than as action goals to accomplish. Learners are less actively involved in the learning process when this happens and are less likely to develop the problem-solving skills needed to become independent learners.

The second reason to distinguish the different levels of study is that not all people can accomplish the action goal using the same movement pattern or perform the same movement using the same neuromotor processes. Learners must discover a movement pattern that is effective and efficient given their unique characteristics, including body size, injuries, disabilities, abilities, fitness, prior learning, and psychological attributes among many others. The effective teacher or therapist acknowledges this diversity and helps the learner to discover the most suitable way to perform a skill. Even world-class athletes come up with unique ways to accomplish the skills within their sports. For example, Hall of Fame basketball player, Rick Barry, made 90% of his free throws during his 14-year professional career by tossing the ball "granny style" with two hands. Similarly, Dick Fosbury revolutionized the sport of high jumping when he introduced his "Fosbury Flop" at the 1968 Mexico City Olympics.

The third reason to distinguish the different levels of study is that different measures are used to evaluate what's happening at each level of study. Given the order in which the different levels are prioritized during motor control and learning this implies that different measures might be taken to assess learning at different stages of practice. In addition, researchers are often interested in asking questions about motor control and learning that require different levels of study. These questions can only be answered by selecting measures that are appropriate for that level of study. In chapter 2 you will see examples of the many different types of measures used to characterize actions, movements, and neuromotor processes.

ONE-DIMENSION CLASSIFICATION SYSTEMS

We can classify motor skills by determining which skill characteristics are similar to those of other skills. The most prevalent approach has been to categorize skills according to one common characteristic. This common characteristic is divided into two categories, which represent extreme ends of a continuum rather than dichotomous categories (as illustrated in figure 1.2). This continuum approach allows a skill to be classified in terms of which category the skill characteristic is more like, rather than requiring that the characteristic fit one category exclusively.

Consider an analogy. The concepts "hot" and "cold" represent two categories of temperatures. Although we typically consider them as distinct categories, we also can view hot and cold as words describing opposite ends of a temperature continuum, because there are degrees of hot or cold that do not fit exclusively into one or the other category. By considering hot and cold as anchor points on a continuum, we can maintain the category distinctions, while at the same time we can more accurately classify various temperature levels that do not fit into only one or the other category.

We will consider three motor skill classification systems that use the one-dimension approach to categorize skills. These classification systems are summarized in figure 1.2.