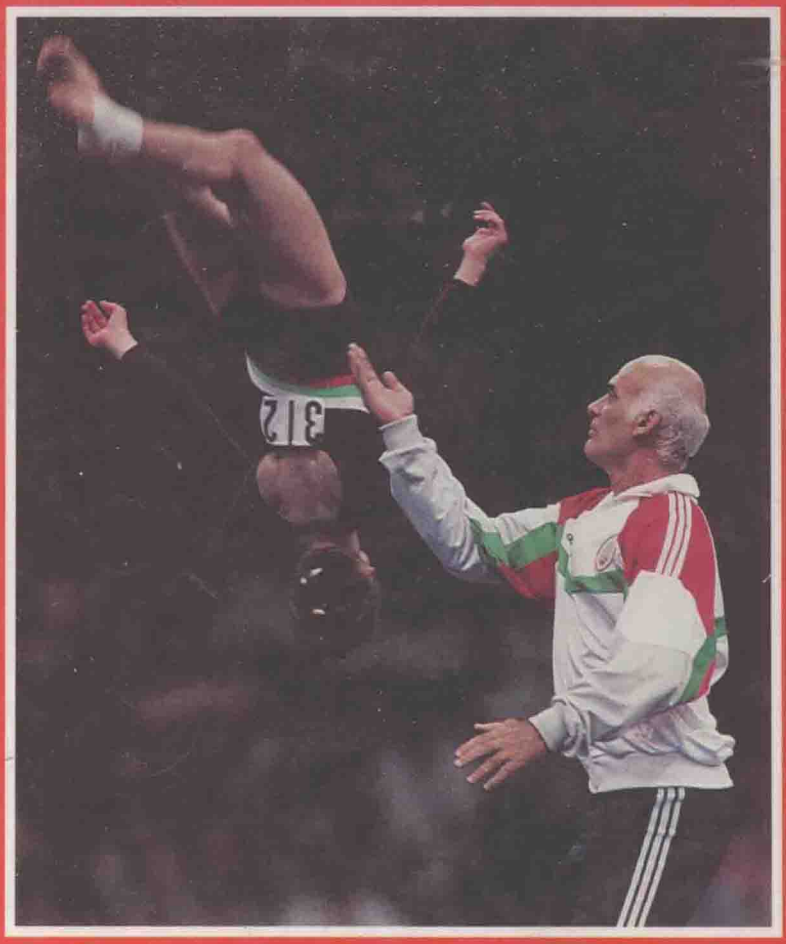
MOTOR LEARNING & PERFORMANCE

FROM PRINCIPLES TO PRACTICE



RICHARD A. SCHMIDT

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◇ FROM PRINCIPLES TO PRACTICE ◇

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This text is dedicated to the memory of
Virginia S. Schmidt
and
Allen W. Schmidt,
as a small thanks for all the skills they taught me.

Preface

For many, there are few things as exciting as a close race, match, or game where the competitors demonstrate nearly incredible levels of skill to achieve victory. For many, there are few things as beautiful as a highly complex, well-controlled skilled action that achieves the performer's exact, intended goal. And, for many, there are few things as satisfying as having been committed to a long-term program of training and skill learning, and then experiencing the thrill of achieving the goal in an important performance.

This book is written for people who feel this kind of excitement about motor skill, and who would like to learn more about the processes underlying skilled performance, how skilled performances are learned, and how to apply the principles of skilled performance and learning in teaching, coaching, and rehabilitation settings. This book is also written for those who have never before considered the complexities involved in teaching motor skills or coaching for maximum performance. This is an introductory text in motor performance and learning for undergraduate college or university students in fields such as physical education, kinesiology, education, psychology, the sport sciences, and physical and occupational therapy. It is intended as a textbook for courses in elementary motor learning or motor behavior. The level of the text is elementary, assuming little prior knowledge of physiology, psychology, statistical methods, or other basic sciences. The concepts from these fields that are critical to understanding motor behavior are introduced as needed, so the flow of the text is not interrupted by these basic background materials.

This text is very different from anything I have tried to write before, and I experienced some difficulty achieving a proper balance between several competing goals. I struggled with decisions about style, organization, and content, and it will be clear that I achieved some goals more effectively than others.

My first goal was to build a strong conceptual understanding of skills, what I term a *conceptual model of human performance*. I started with a simple model of the performer as an information processor, then gradually added elements to the model as they were discussed, and concluded with a larger, integrated, conceptual model that goes beyond the original information processing approach. Upon completion of Part I, the student should have a reasonably coherent view of the conceptual, functional properties of the motor system. A student with a general understanding of how skills operate, the major principles for performance, and how the human motor system learns, will best be able to apply this knowledge to real-world settings. These principles will be most appropriate for maximizing the performance of already learned skills, which typically occurs in coaching settings.

Part II of the text uses this conceptual model to impart an understanding of human motor learning processes. Much of this discussion uses the terms and principles introduced relative to motor behavior in the earlier chapters. This method works well in my own teaching, probably because motor learning is really inferred from changes in motor behavior; it is easy to discuss these changes in terms of the behavioral principles. By the end of the text, there has been

a progressive accumulation of knowledge that, in my experience, provides a consistent view of how skills are performed and learned. The applications presented in Part III are more aligned with teaching, focusing on the structure of practice for effective skill acquisition.

Second, I wanted to write a text that could be used by performers, teachers, coaches, and physical therapists to enhance human performance in real-world settings in physical education, sport, athletics, and rehabilitation. This goal demanded careful scrutiny of the many topics presented in these areas. Those topics most relevant to practical application were emphasized, whereas those of less practical interest were excluded.

Many examples of each principle are discussed in the main body of the text. In addition, all the chapters include Practical Applications sections set off from the main textual materials. Strategically located directly after pertinent discussions of principles, these sections indicate applications to real-world teaching, coaching, or therapy settings.

Third, I wanted a presentation style that was simple, straightforward, and easy to read for those without extensive backgrounds in the motor performance area. As a result, the main content does not greatly stress the research and data that contribute to our knowledge of motor skill acquisition and performance. Important points are occasionally illustrated by data from a critical experiment, but the focus is on an integrated conceptual knowledge of how the motor system works and how it learns. However, for those who desire a tighter link to the basic data, I have included sections called Highlight Boxes which describe the important experiments and concepts in detail. At the end of each chapter, I also present a set of self-test questions and a list of key terms as comprehension checks for the reader.

Finally, I demanded that the principles discussed should be faithful to the empirical data and thought in the study area. This goal is not immediately obvious when viewing the text because there are relatively few references cited and few experiments discussed. From my 25 years doing basic research in learning and performance, I have developed what I believe to be a defensible, coherent personal viewpoint (a conceptual model, if you will) about how skills are performed and learned, and my goal is to present this model to the reader to facilitate understanding. My viewpoint is based on a large literature of theoretical ideas and empirical data, together with much thought about competing ideas and apparently contradictory research findings. I have tried to write my perspective as I would tell a story. Every part of the story can be defended, or it would not have been included, but I have not been willing to interrupt the story with justifications, rationales, and critical evidence for most of the points. My goal has been to write the "truth," at least as I understand it, and as it can be understood with our current level of knowledge. I have included at the end of each chapter a brief section describing additional readings, where competing viewpoints and additional scientific justifications can be found.

Thanks should be expressed to several people who helped with this text. First, my longtime friend Rainer Martens was instrumental in convincing me, over several years, that I could actually write such a text. He gave me many concrete suggestions and encouraged my initial efforts; the text would not have happened without his help. Thanks are extended to Gwen B. Gordon for her understanding and encouragement throughout. I would like to thank acquisitions editor Rick Frey, who provided many good suggestions and much encouragement early on in the writing process, and developmental edi-

tor Judy Patterson Wright for her critical but constructive comments on the first draft, which became the basis of many fundamental revisions. Appreciation is also extended to Tim Lee and to four anonymous reviewers for their helpful comments on earlier drafts of the manuscript.

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Westwood, California

Contents

1 Introduction to Motor Performance and Learning

PREVIEW

In the 1970s a petite Russian girl named Olga Korbut captivates the sports world with her feats in women's gymnastics at the Olympic Games, and she becomes a role model for many young girls who suddenly want to learn gymnastics. In the 1980s Jim Knaub, who had lost the use of his legs in an accident, wins several important marathons in the wheelchair division, earning our admiration and respect. From the 1970s into the '90s, David Kiley (shown above) earns the title of ''The King of Wheelchair Sports'' by winning five gold medals in the 1976 Paralympic Games in Canada, climbing the highest mountain in Texas, and playing on the United States Men's Wheelchair Basketball team five times, as well as by being a top competitor in tennis, racquetball, and skiing. On New Year's Day in 1990, over 105,000 enthusiastic people crowd into a stadium in Pasadena, California, to watch the Rose Bowl football game, and millions more watch the

television broadcast. These and many other examples indicate that skills—particularly skills involved in sport—are a critical part of human existence. How people can perform at such high levels, how such skills are developed, and how you can develop some approximation of these skills in yourself, your children, or your students—all of these questions generate fascination, encouraging further learning about human movement.

Here begins a description of the study of motor performance and learning, introducing the concept of skill and discussing various features of its definition. Next the text examines skill classification schemes important for later applications. Finally, to help you understand skills effectively using this book, the logic behind its organization is described: the principles and processes underlying skilled performance, followed by how to develop such capabilities with practice.

STUDENT GOALS

1. To appreciate the varieties of skills and their structures
2. To understand the many aspects of a definition of skill
3. To recognize several classifications of skills
4. To understand the textbook's organization: motor performance followed by learning

The remarkable human capability to perform skills is a critical feature of our very existence. It is almost uniquely human in nature, although various animals high on the evolutionary scale can produce what you might call skilled behaviors (e.g., circus dogs who do complex tricks). Without the capacity for skilled performance, I could not type the page I am preparing now and you could not read it. And for students involved in physical education, coaching, or kinesiology, there would not be the wide variety of sports and athletic endeavors that are so strongly fascinating and exciting.

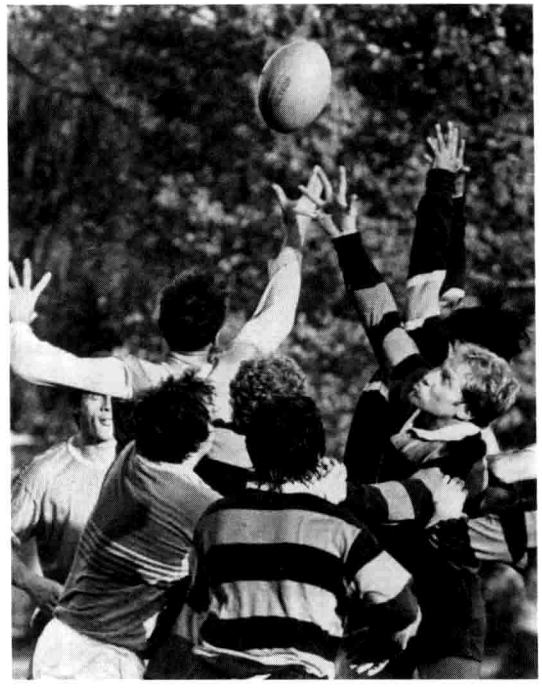
Human skills take many forms, of course, from those that emphasize the control and coordination of our largest muscle groups, in relatively forceful activities like soccer or tumbling, to those in which the smallest muscle groups must be tuned precisely, as in typing or repairing a watch. This text generally focuses on the full range of skilled behavior because it is useful to understand that many common features underlie the performance of skills associated with industrial and military settings, sports, the re-acquisition of movement capabilities lost through injuries or stroke, or simply the everyday activities of most people. But the major focus is on skilled performances applicable to sports, games, dance, and similar activities that make up so large a part of the scope of human skills.

Most humans are born with the capability to produce many skills, and only a little maturation and experience is necessary in order to produce them in nearly complete form.

Walking and running, chewing, balancing, and avoiding painful stimuli are some examples of these relatively innate behaviors. But imagine what simple and uninteresting creatures we would be if these inherited actions were all that we could ever do. All biological organisms have the remarkable facility to profit from their experiences, to learn to detect important environmental features (and to ignore others), and to produce behaviors that were not a part of their original capabilities. Humans have the most flexibility of all, which allows gaining proficiency for occupations as chemists or computer programmers, for competition in music or athletics, or simply for conducting daily lives more efficiently. Thus, producing skilled behaviors and the learning that leads to their development are tightly intertwined in human experience. This book is about both of these aspects of skills—skilled human performance and human learning.

APPLICATIONS OF KNOWLEDGE ABOUT SKILLS

Because skills make up such a large part of human life, scientists and educators have been trying for centuries to understand the determinants of skills and the factors that affect their performance. The knowledge gained has provided applications to numerous aspects of life, including improving performance in sports and physical activities. Important points apply to the instructional aspects of physical education, where methods for efficient skills teaching and effective carryover to life situations are primary concerns. Also, considerable applicability is possible for improving high-level sports performances and every other kind of physical activity. Of course, much of what coaches do during practices involves, in one way or another, skills instruction. Those coaches who understand these processes most effectively undoubtedly have an advantage when their athletes take the field.



Human skilled performance involving cooperation among team members.

Other application areas can be emphasized as well. There are many applications in training skills for industry, where effective job skills can mean success in the workplace and be major determinants of satisfaction both with the job and with life in general. Teaching job skills most effectively and determining which individuals are best suited to particular occupations are typical situations where knowledge about skills can be useful in industry.

The principles are applicable to physical therapy and occupational therapy settings as well, where the concern is for the (re)learning

and production of movements that have been lost through head or spinal cord injury, stroke, birth defects, and the like. Although all these areas may be different and the physical capabilities of the learners may vary widely, the principles that lead to successful application are generally the same.

Human skilled performance involving motor control in a therapeutic setting.

SKILL DEFINITIONS

As widely represented and diverse as skills are, it is difficult to define them in a way that applies to all cases. The psychologist E.R. Guthrie (1952) has provided a definition that captures most of the critical features of skills:

> **Skill** consists in the ability to bring about some end result with maximum certainty and minimum outlay of energy, or of time and energy. (p. 136)

There are several important features of this definition to consider. First, performing skills implies some desired environmental goal, such as holding a handstand in gymnastics or completing a forward pass in football. Skills are usually thought of as different from movements, which do not necessarily have any particular environmental goal, such as idly wiggling my little finger. Of course, skills *consist* of movements because the performer could not achieve an environmental goal without making at least one movement.

Second, to be skilled implies meeting this performance goal, this "end result," with maximum certainty. For example, last month while playing darts I made a bull's-eye. But this by itself does not ensure that I am a skilled darts player, because I have not demonstrated that I can achieve this result with any certainty. Such an outcome was the result of one lucky throw in the midst of hundreds of others that were not so lucky. I need to demonstrate that I can produce the skill reliably, on demand, without luck playing a very large role. This is why people so greatly value the champion athlete who, with but one chance and only seconds remaining at the end of a game, makes the goal that allows the team to win.

Third, a major feature in many skills is the minimization, and thus conservation, of the energy required for performance. For some skills this is clearly not the goal, such as in the shot put, where the only goal is to throw the maximum distance. But for many other skills the minimization of energy expenditure is critical, allowing the marathon runner to hold an efficient pace or allowing the wrestler to save strength for the last few minutes of the match. This minimum-energy notion applies to organizing the action not only so the physiological energy costs are lower but also so the psychological, or mental, energy required is reduced. Many skills have been learned so well that the performers hardly have to pay attention to them, freeing their cognitive processes for other features of the

activity, such as strategy in basketball or expressiveness in dance. A major contributor to the efficiency of skilled performance is practice, with learning and experience leading to the relatively effortless performances so admired in highly skilled people.

Finally, another feature of many skills is for highly proficient performers to achieve their goals in minimum time. Many sports skills have this as the only competition goal, such as a swimming race. Other skills are more effective if done quickly, such as a boxing jab or a basketball pass. Minimizing time can interact with the other skill features mentioned, however. Speeding up performance often results in sloppy movements that have less certainty in terms of achieving the environmental goal. Also, increased speed generates movements for which the energy costs are sometimes higher. Thus, understanding skills involves optimizing and balancing several skill aspects that are important to different extents in different settings.

In sum, skills generally involve achieving some well-defined environmental goal by

- maximizing the achievement certainty,
- minimizing the physical and mental energy costs of performance, and
- minimizing the time used.

THE MANY COMPONENTS OF SKILLS

The elegant performance of the skilled dancer and the winning actions of an Olympic weight lifter may appear simple, but the performance goals actually were realized through a complex combination of interacting mental and motor processes. For example, many skills involve considerable emphasis on sensory-perceptual factors, such as detecting that a tennis opponent is going to hit a shot to the left or that a baseball pitch is curving. Often, sensory factors require the split-second analysis of patterns of sensory input, such as discerning that the combined movements of an entire football team indicate the play will be a run to the left side. These perceptual events lead to decisions about what to do, how to do it, and when to do it. These decisions are often a major determinant of success, as in deciding whether to take a shot in basketball or where to throw the baseball after fielding a hit. Finally, of course, skills typically depend on the quality of movement generated as a result of these decisions. Even if the situation is correctly perceived and the response decisions are appropriate, the performer will not be effective in meeting the environmental goal if he or she executes the actions poorly.

These three elements are critical to almost any skill:

- Perceiving the relevant environmental features
- Deciding what to do and where and when to do it
- Producing organized muscular activity to generate movements

The movements have several recognizable parts. Postural components support the actions; for instance, the arms of an archer need to be supported by a stable platform to shoot accurately. Body transport, or locomotor, components move the body toward the point where the skill will take place, as in setting for a return on the tennis court, or moving a limb toward a place where the action can occur, as in grasping the horizontal bar after a release. Finally, manipulation components are coupled and coordinated with these other elements and can make up the major focus of the skill, such as the finger and wrist movements in a complex video game.

Here are summarized the three major

kinds of components involved in the production of many skills:

- Postural components provide a "platform" to support the actions
- Body transport components bring the body or limb to the action
- Manipulation components produce the action

It is interesting, but perhaps unfortunate, that each of these skill components seems to be recognized and studied in isolation from the others. For example, sensory factors in perception are studied by cognitive psychologists, scientists interested in (among other things) the complex information-processing activities involved in seeing, hearing, and feeling. Sometimes these factors are in the realm of psychophysics, the branch of psychology that examines the relationship between objective physical stimuli (e.g., vibration intensity) and the subjective sensations these stimuli create when perceived (loudness). Decision-making processes are typically of interest to a different group of scientists in cognitive and experimental psychology. Factors in the control of the movement itself are typically handled by scientists in the neurosciences, kinesiology, biomechanics, physical education, and physiology, often with little concern for the perceptual and decision-making processes. Skill learning is studied by yet another group of scientists in kinesiology or in experimental or educational psychology. A major problem for the study of skills, therefore, is the fact that the several components of skill are studied by widely different groups of scientists, generally with little overlap and communication among them.

To summarize, these are the major processes underlying actions:

1. Sensory or perceptual processes, studied in cognitive psychology and psychophysics;
2. Decision-making processes, studied in cognitive and experimental psychology;
3. Motor-control or movement-production processes, studied in the neurosciences, kinesiology, bioengineering, biomechanics, physical education, and physiology; and
4. Learning processes, studied in kinesiology, physical education, and educational and experimental psychology.

All of these various processes are present in almost all motor skills. Even so, we should not get the idea that all skills are fundamentally the same. In fact, the principles of human performance and learning depend to some extent on the kind of movement skill to be performed. So, the ways that skills have been classified are discussed next.

SKILL CLASSIFICATIONS

There are several skill classification systems that help organize the research findings and make application somewhat more straightforward. These are presented in the following sections.

Open and Closed Skills

One way to classify movement skills concerns the extent to which the environment is stable and predictable throughout performance. An **open skill** is one for which the environment is variable and unpredictable during the action. Examples include carrying the ball against a defensive team in American football, and wrestling, where it is difficult to predict the future moves of the opponent (and hence future responses to the opponent) very effectively. A **closed skill**, on the other hand, is one for which the environment is stable and predictable. Examples include gymnastics routines and swimming in

an empty lane in a pool. These "open" and "closed" designations actually only mark the end points of a spectrum, with skills lying between having varying degrees of environmental predictability or variability.

This classification points out a critical feature for skills, defining the performer's need to respond to moment-to-moment variations in the environment. It thus brings in the processes associated with perception, pattern recognition, and decision making (usually with the need to perform these processes quickly) so the action can be tailored to the environment. These processes are supposedly minimized in closed skills, where the performer can evaluate the environmental demands in advance without time pressure, organize the movement in advance, and carry it out without needing to make rapid modifications as the movement unfolds. These features are summarized in Table 1.1.

Table 1.1 Open-Closed Skill Dimension

Closed skills		Open skills
Predictable environment	Semipredictable environment	Unpredictable environment
Gymnastics	Walking a tightrope	Playing soccer
Archery	Steering a car	Wrestling
Typing	Playing chess	Chasing a rabbit

Discrete, Continuous, and Serial Skills

A second scheme for classifying skills concerns the extent to which the movement is an ongoing stream of behavior, as opposed to a brief, well-defined action. At one end of this dimension is a **discrete skill**, which usually has an easily defined beginning and end, often with a very brief duration of movement, such as throwing or kicking a ball, firing a rifle, or catching a pass. Discrete skills are particularly important in sport performances, especially considering the large number of discrete hitting, kicking, throwing, and catching skills that make up many popular games and sport activities.

At the other end of this dimension is a **continuous skill**, which has no particular beginning or end, the behavior flowing on for many minutes, such as swimming, running, or pedaling a bicycle. One particularly important continuous skill is tracking, in which the performer's limb movements control a lever, a wheel, a handle, or some other device to follow the movements of some target track. Steering a car is tracking, with steering wheel movements made so the car follows the track defined by the roadway. Tracking movements are very common in real-world skills situations, and much research has been directed to their performance and learning. As discussed later, discrete and continuous skills can be quite different, requiring different processes for performance and demanding that they be taught and coached somewhat differently as a result.

Between the polar ends of the discrete-continuous dimension is the **serial skill**, which is often thought of as a group of discrete skills strung together to make up a new, more complicated skilled action. See Table 1.2 for a comparison summary. Here the word *serial* implies that the order of the elements is usually critical for successful performance. Shifting car gears is a serial skill, with three discrete shift lever action elements (and accelerator and clutch elements) connected in sequence to create a larger action. Other examples include performing a gymnastics routine and following the sequential gates in a skiing race. Serial skills differ from discrete

skills in that the movement durations are somewhat longer, yet each movement retains a discrete beginning and end. One view of learning serial skills suggests that the individual skill elements present in early learning are somehow combined to form one larger, single element that the performer controls almost as if it were truly discrete in nature (e.g., the smooth, rapid way a race-car driver shifts gears).

Table 1.2 Discrete-Serial-Continuous Skill Dimension

Discrete skills	Serial skills	Continuous skills
Distinct beginning and end	Discrete actions linked together	No distinct beginning or end
Throwing a dart	Hammering a nail	Steering a car
Catching a ball	Assembly-line task	Swimming
Shooting a rifle	Gymnastics routine	Tracking task

Motor and Cognitive Skills

It is sometimes useful to consider a third dimension, labeled motor and cognitive skills. With a **motor skill** the primary determinant of success is the quality of the movement itself, where perception and subsequent decisions about which movement to make are nearly absent. For example, the high jumper knows exactly what to do (jump over the bar), but the problem is that the movements must be made effectively in order that maximum height be achieved.

On the other hand, with a **cognitive skill** the nature of the movement is not particularly important, but the decisions about which movement to make are critical. For example, in chess it matters little whether the pieces are moved quickly and smoothly; rather, it is important that the player know which piece to move where and when, to maximize the gain against the opponent.

In short, a cognitive skill mainly involves selecting what to do, whereas a motor skill mainly involves how to do it. This dimension, like the others, is really a continuum because there is no completely cognitive skill or completely motor skill (see Table 1.3). Every skill, no matter how cognitive it might seem, requires at least some motor output,

Table 1.3 Motor-Cognitive Skill Dimension

Motor skills		Cognitive skills
Decision making minimized	Some decision making	Decision making maximized
Motor control maximized	Some motor control	Motor control minimized
High jumping	Playing quarterback	Playing chess
Pitching	Driving a race car	Cooking a meal
Weight lifting	Sailing an iceboat	Coaching a sport