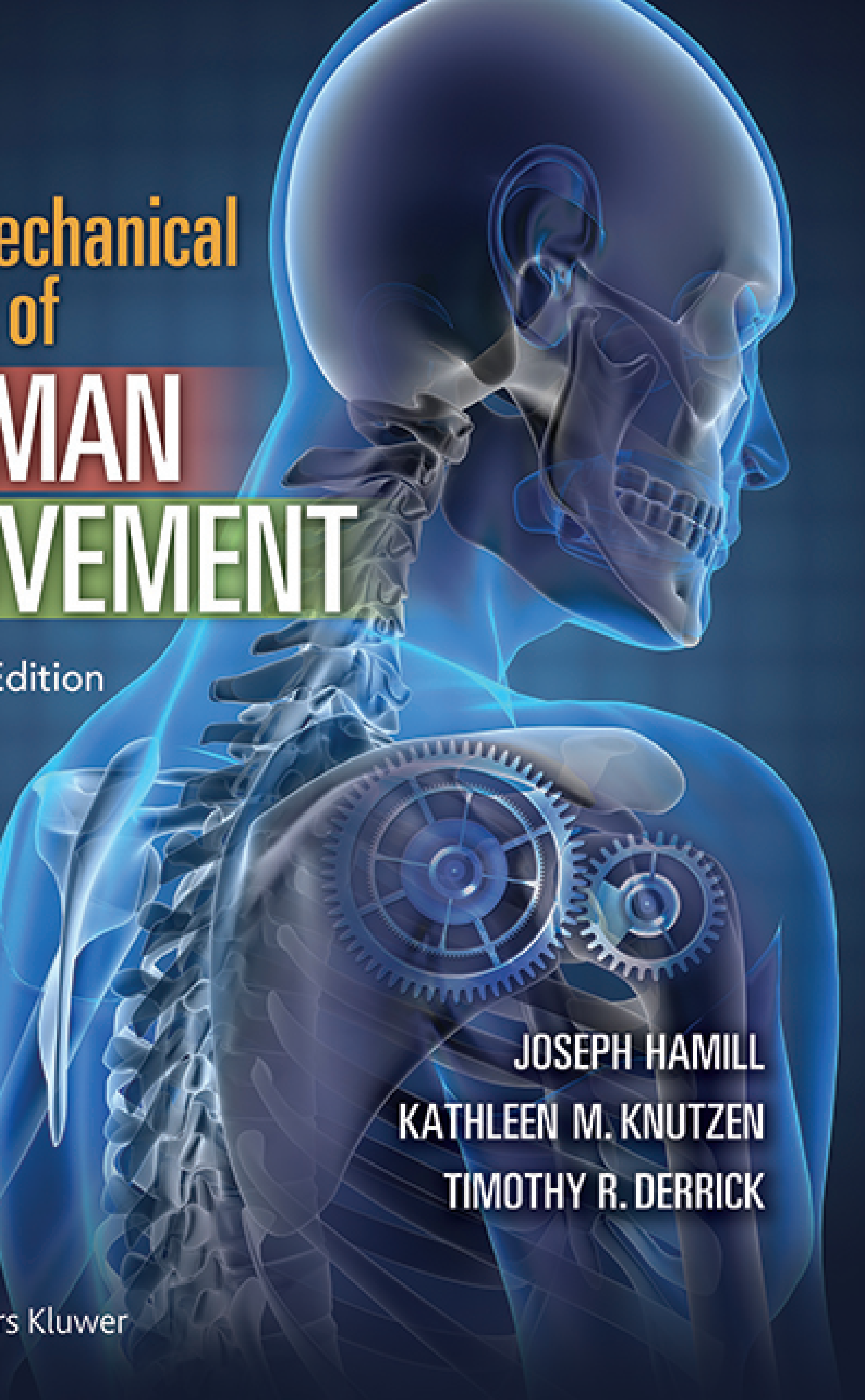
Biomechanical Basis of HUMAN MOVEMENT

Fourth Edition



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Wolters Kluwer

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To our friend and mentor B.T. Bates,
and to our families.

Preface

Biomechanics is a quantitative field of study within the discipline of exercise science. This book is intended as an introductory textbook that stresses this quantitative (rather than qualitative) nature of biomechanics. It is hoped that, while stressing the quantification of human movement, this fourth edition of *Biomechanical Basis of Human Movement* will also acknowledge those with a limited background in mathematics. The quantitative examples are presented in a detailed, logical manner that highlight topics of interest. The goal of this book, therefore, is to provide an introductory text in biomechanics that integrates basic anatomy, physics, calculus, and physiology for the study of human movement. We decided to use this approach because numerical examples are meaningful and easily clear up misconceptions concerning the mechanics of human movement.

Organization

This book is organized into three major sections: Part I: Foundations of Human Movement; Part II: Functional Anatomy; and Part III: Mechanical Analysis of Human Motion. The chapters are ordered to provide a logical progression of material essential toward the understanding of biomechanics and the study of human movement.

Part I, Foundations of Human Movement, includes Chapters 1 through 4. Chapter 1, "Basic Terminology," presents the terminology and nomenclature generally used in biomechanics. Chapter 2, "Skeletal Considerations for Movement," covers the skeletal system with particular emphasis on joint articulation. Chapter 3, "Muscular Considerations for Movement," discusses the organization of the muscular system. Finally, in Chapter 4, "Neurologic Considerations for Movement," the control and activation systems for human movement are presented. In this edition, some of the foundation material was reorganized and new material was added in areas such as physical activity and bone formation, osteoarthritis, osteoporosis, factors influencing force and velocity development in the muscles, and the effect of training on muscle activation.

Part II, Functional Anatomy, includes Chapters 5 through 7 and discusses specific regions of the body: the upper extremity, lower extremity, and trunk, respectively. Each chapter integrates the general information presented in Part I relative to each region. In this edition, the information on muscles and ligaments was moved from the appendix into the chapter text to facilitate review of muscle and ligament locations and actions. The exercise section was reorganized to provide samples of common exercises used for each region. Finally, the analysis of selected activities at the end of each chapter includes a more comprehensive muscular analysis based on the results of electromyographic studies.

Part III, Mechanical Analysis of Human Motion, includes Chapters 8 through 11, in which quantitative mechanical techniques for the analyses of human movement are presented. Chapters 8 and 9 present the concepts of linear and angular kinematics. Conventions for the study of linear and angular motion in the analysis of human movement are also detailed in these two chapters. A portion of each chapter is devoted to a review of the research literature on human locomotion, wheelchair locomotion, and golf. These activities are used throughout Part III to illustrate the quantitative techniques presented. Chapters 10 and 11 present the concepts of linear and angular kinetics, including discussions on the forces and torques that act on the human body during daily activities. The laws of motion are provided and explained. Included here is a discussion of the forces and torques applied to the segments of the body during motion.

Although the book follows a progressive order, the major sections are generally self-contained. Therefore, instructors may delete or deemphasize certain sections. Parts I and II, for example, could be used in a traditional kinesiology course, and Part III could be used for a biomechanics course.

Features

Each chapter contains a list of **Chapter Objectives** to enable the student to focus on key points in the material, and **Chapter Outlines** provide a guide to the content discussed. **Boxes** are included throughout to highlight important material, and relevant **Questions** are pulled out to help the student briefly review a concept. **Chapter Summaries** at the end of each chapter recap the major concepts presented. Each chapter contains **Review Questions**, both true/false and multiple choice, to challenge students and help them digest and integrate the material presented. A **Glossary** is presented at the end of this book, defining terms found in each chapter and to be used as a source of reinforcement and reference. Finally, four appendices present information on units of measurement, trigonometric functions, and hands-on data.

Illustrations of the principles of human movement are easily seen in most sports examples, but in this edition of *Biomechanical Basis of Human Movement*, new and updated illustrations include applications from ergonomics, orthopedics, and exercise. These are supplemented with references from the current biomechanics literature. With these and the content and features mentioned above, the full continuum of human movement potential is considered.

Additional Resources

Biomechanical Basis of Human Movement, Fourth Edition, includes additional resources for both instructors and students that are available on the book's companion web site at http://thePoint.lww.com/hamill4e.

INSTRUCTORS

Approved adopting instructors will be given access to the following additional resources:

- Brownstone test generator
- PowerPoint presentations
- Image bank
- WebCT and Blackboard Ready Cartridges

STUDENTS

Students who have purchased the text have access to the following additional resources:

- Answers to the review questions in the text
- Student practice quizzes
- MaxTRAQ motion analysis software, accessible via hyperlink from thePoint

See the inside front cover of this text for more details, including the passcode you will need to gain access to the website.

Acknowledgments

To those who reviewed this edition of the book and who made a substantial contribution to its development, we express our sincere appreciation. We also thank Kristin Royer (product manager), Emily Lupash (acquisitions editor), and Shauna Kelley (marketing manager) of Wolters Kluwer Health/Lippincott Williams & Wilkins for their expertise throughout the publishing process. A special thanks to Nic Castona and Nike, Inc., for the photography used throughout.

Contents

SECTION 1

FOUNDATIONS OF HUMAN MOVEMENT

CHAPTER 1

BASIC TERMINOLOGY

OBJECTIVES

After reading this chapter, the student will be able to:

1. Define mechanics, biomechanics, and kinesiology, and differentiate among their uses in the analysis of human movement.
2. Define and provide examples of linear and angular motion.
3. Define kinematics and kinetics.
4. Describe the location of segments or landmarks using correct anatomical terms, such as medial, lateral, proximal, and distal.
5. Identify segments by their correct names, define all segmental movement descriptors, and provide specific examples in the body.
6. Explain the difference between relative and absolute reference systems.
7. Define sagittal, frontal, and transverse planes along with corresponding frontal, sagittal, and longitudinal axes. Provide examples of human movements that occur in each plane.
8. Explain degree of freedom, and provide examples of degrees of freedom associated with numerous joints in the body.

OUTLINE

Core Areas of Study
- Biomechanics versus Kinesiology
- Anatomy versus Functional Anatomy
- Linear versus Angular Motion
- Kinematics versus Kinetics
- Statics versus Dynamics

Anatomical Movement Descriptors
- Segment Names
- Anatomical Terms
- Movement Description

Reference Systems
- Relative versus Absolute
- Planes and Axes

Summary

Review Questions

To study kinesiology and biomechanics using this textbook requires a fresh mind. Remember that human movement is the theme and the focus of study in both disciplines. A thorough understanding of various aspects of human movement may facilitate better teaching, successful coaching, more observant therapy, knowledgeable exercise prescription, and new research ideas. Movement is the means by which we interact with our environment, whether we are simply taking a walk in a park, strengthening muscles in a bench press, competing in the high jump at a collegiate track meet, or stretching or rehabilitating an injured joint. Movement, or motion, involves a change in place, position, or posture relative to some point in the environment.

This textbook focuses on developing knowledge in the area of human movement in such a manner that you will feel comfortable observing human movement and solving movement problems. Many approaches can be taken to the study of movement, such as observing movement using only the human eye or collecting data on movement parameters using laboratory equipment. Observers of activities also have different concerns: A coach may be interested in the outcome of a tennis serve, but a therapist may be interested in identifying where in the serve an athlete with tendinitis is placing the stress on the elbow. Some applications of biomechanics and kinesiology require only a cursory view of a movement such as visual inspection of the forearm position in the jump shot. Other applications, such as evaluating the forces applied by a hand on a basketball during a shot, require some advanced knowledge and the use of sophisticated equipment and techniques.

Elaborate equipment is not needed to apply the material in this text but is necessary to understand and interpret numerical examples from data collected using such intricate instruments. Qualitative examples in this text describe the characteristics of movement. A **qualitative analysis** is a nonnumeric evaluation of motion based on direct observation. These examples can be applied directly to a particular movement situation using visual observation or video.

This text also presents quantitative information. A **quantitative analysis** is a numeric evaluation of the motion based on data collected during the performance. For example, movement characteristics can be presented to describe the forces or the temporal and spatial components of the activity. The application of this material to a practical setting, such as teaching a sport skill, is more difficult because it is more abstract and often cannot be visually observed. Quantitative information can be important, however, because it often substantiates what is seen visually in a qualitative analysis. It also directs the instructional technique because a quantitative analysis identifies the source of a movement. For example, a front handspring can be qualitatively evaluated through visual observation by focusing on such things as whether the legs are together and straight, the back is arched, and the landing is stable and whether the handspring was too fast or slow. But it is through the quantitative analysis that the source of the movement, the magnitude of the forces generated, can be identified. A force cannot be observed qualitatively, but knowing it is the source of the movement helps with qualitative assessment of its effects, that is, the success of the handspring.

This chapter introduces terminology that will be used throughout the remainder of the text. The chapter begins by defining and introducing the various areas of study for movement analysis. This will be the first exposure to the areas presented in much greater depth later in the text. Then the chapter discusses methods and terminology describing how we arrive at the basic mechanical properties of various structures. Finally, the chapter establishes a working vocabulary for movement description at both structural and whole-body levels.

Core Areas of Study

BIOMECHANICS VERSUS KINESIOLOGY

Those who study human movement often disagree over the use of the terms *kinesiology* and *biomechanics*. Kinesiology can be used in one of two ways. First, **kinesiology** as the scientific study of human movement can be an umbrella term used to describe any form of anatomical, physiologic, psychological, or mechanical human movement evaluation. Consequently, kinesiology has been used by several disciplines to describe many different content areas. Some departments of physical education and movement science have gone so far as to adopt *kinesiology* as their department name. Second, kinesiology describes the content of a class in which human movement is evaluated by examination of its source and characteristics. However, a class in kinesiology may consist primarily of functional anatomy at one university and strictly biomechanics at another.

Historically, a kinesiology course has been part of college curricula as long as there have been physical education and movement science programs. The course originally focused on the musculoskeletal system, movement efficiency from the anatomical standpoint, and joint and muscular actions during simple and complex movements. A typical student activity in the kinesiology course was to identify discrete phases in an activity, describe the segmental movements occurring in each phase, and identify the major muscular contributors to each joint movement. Thus, if one were completing a kinesiological analysis of the act of rising from a chair, the movements would be hip extension, knee extension, and plantarflexion via the hamstrings, quadriceps femoris, and triceps surae muscle groups, respectively. Most kinesiological analyses are considered qualitative because they involve observing a movement and providing a breakdown of the skills and identification of the muscular contributions to the movement.

The content of the study of kinesiology is incorporated into many biomechanics courses and is used as a precursor to the introduction of the more quantitative biomechanical content. In this text, *biomechanics* will be used as an umbrella term to describe content previously covered in courses in kinesiology as well as content developed as a result of growth of the area of biomechanics.

In the 1960s and 1970s, biomechanics was developed as an area of study in undergraduate and graduate curricula across North America. The content of biomechanics was extracted from mechanics, an area of physics that consists of the study of motion and the effect of forces on an object. Mechanics is used by engineers to design and build structures and machines because it provides the tools for analyzing the strength of structures and ways of predicting and measuring the movement of a machine. It was a natural transition to take the tools of mechanics and apply them to living organisms. Biomechanics is the study of the structure and function of biological systems by means of the methods of mechanics (1). Another definition proposed by the European Society of Biomechanics (2) is "the study of forces acting on and generated within a body and the effects of these forces on the tissues, fluid, or materials used for the diagnosis, treatment, or research purposes."

A biomechanical analysis evaluates the motion of a living organism and the effect of forces on the living organism. The biomechanical approach to movement analysis can be qualitative, with movement observed and described, or quantitative, meaning that some aspect of the movement will be measured. The use of the term *biomechanics* in this text incorporates qualitative components with a more specific quantitative approach. In such an approach, the motion characteristics of a human or an object are described using parameters such as speed and direction; how the motion is created through application of forces, both inside and outside the body; and the optimal body positions and actions for efficient and effective motion. For example, to biomechanically evaluate the motion of rising from a chair, one attempts to measure and identify joint forces acting at the hip, knee, and ankle along with the force between the foot and the floor, all of which act together to produce the movement up and out of the chair. The components of a biomechanical and kinesiologic movement analysis are presented in Figure 1-1. We now examine some of these components individually.

ANATOMY VERSUS FUNCTIONAL ANATOMY

Anatomy, the science of the structure of the body, is the base of the pyramid from which expertise about human movement is developed. It is helpful to develop a strong understanding of regional anatomy so that for a specific region such as the shoulder, the bones, arrangement of muscles, nerve innervation of those muscles, and blood supply to those muscles and other significant structures (e.g., ligaments) can be identified. A knowledge of anatomy can be put to good use if, for example, one is trying to assess an injury. Assume a patient has a pain on the inside of the elbow. Knowledge of anatomy allows one to recognize the medial epicondyle of the humerus as the prominent bony structure of the medial elbow. It also indicates that the muscles that pull the hand and fingers toward the forearm in a flexion motion attach to the epicondyle. Thus, familiarity with anatomy may lead to a diagnosis of medial epicondylitis, possibly caused by overuse of the hand flexor muscles.

Functional anatomy is the study of the body components needed to achieve or perform a human movement or function. Using a functional anatomy approach to analyze a lateral arm raise with a dumbbell, one should identify the deltoid, trapezius, levator scapulae, rhomboid, and supraspinatus muscles as contributors to upward rotation and elevation of the shoulder girdle and abduction of the arm. Knowledge of functional anatomy is useful in a variety of situations, for example, to set up an exercise or weight training program and to assess the injury potential in a movement or sport or when establishing training techniques and drills for athletes. The prime consideration

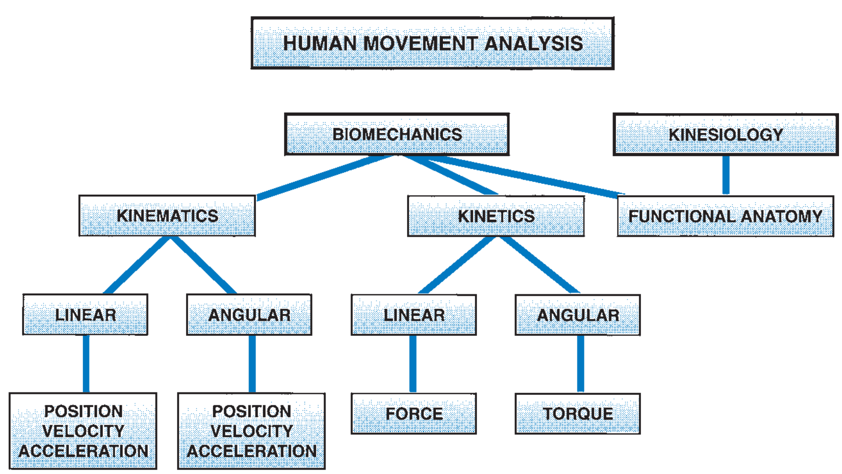


FIGURE 1-1 Types of movement analysis. Movement can be analyzed by assessing the anatomical contributions to the movement (functional anatomy), describing the motion characteristics (kinematics), or determining the cause of the motion (kinetics).

of functional anatomy is not the muscle's location but the movement produced by the muscle or muscle group.

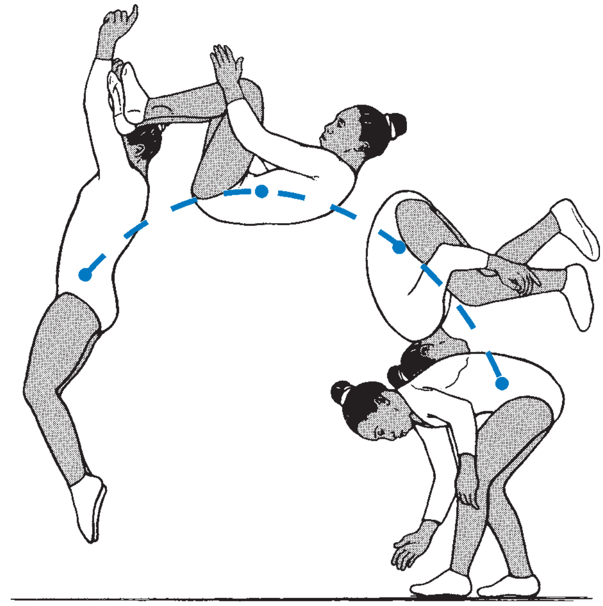
LINEAR VERSUS ANGULAR MOTION

Movement or motion is a change in place, position, or posture occurring over time and relative to some point in the environment. Two types of motion are present in a human movement or an object propelled by a human. First is **linear motion**, often termed *translation* or *translational motion*. Linear motion is movement along a straight or curved pathway in which all points on a body or an object move the same distance in the same amount of time. Examples are the path of a sprinter, the trajectory of a baseball, the bar movement in a bench press, and the movement of the foot during a football punt. The focus in these activities is on the direction, path, and speed of the movement of the body or object. Figure 1-2 illustrates two focal points for linear movement analysis.

The center of mass of the body, of a segment, or of an object is usually the point monitored in a linear analysis (Fig. 1-2). The center of mass is the point at which the mass of the object appears to be concentrated, and it represents the point at which the total effect of gravity acts on the object. However, any point can be selected and evaluated for linear motion. In skill analysis, for example, it is often helpful to monitor the motion of the top of the head to gain an indication of certain trunk motions. An examination of the head in running is a prime example. Does the head move up and down? Side to side? If so, it is an indication that the central mass of the body is also moving in those directions. The path of the hand or racquet is important in throwing and racquet sports, so visually monitoring the linear movement of the hand or racquet throughout the execution of the motion is beneficial. In an activity such as sprinting, the linear movement of the whole body is the most important component to analyze because the object of the sprint is to move the body quickly from one point to another.

The second type of motion is **angular motion**, which is motion around some point so that different regions of the same body segment or object do not move through the same distance in a given amount of time. As illustrated in Figure 1-3, swinging around a high bar represents angular motion because the whole body rotates around the contact point with the bar. To make one full revolution around the bar, the feet travel through a much greater distance than the arms because they are farther from the point of turning. It is typical in biomechanics to examine the linear motion characteristics of an activity and then follow up with a closer look at the angular motions that create and contribute to the linear motion.

All linear movements of the human body and objects propelled by humans occur as a consequence of angular contributions. There are exceptions to this rule such as skydiving or free falling, in which the body is held in a position to let gravity create the linear movement downward, and when an external pull or push moves the body or an object. It is important to identify the angular motions and their sequence that make up a skill or human movement because the angular motions determine the success or failure of the linear movement.



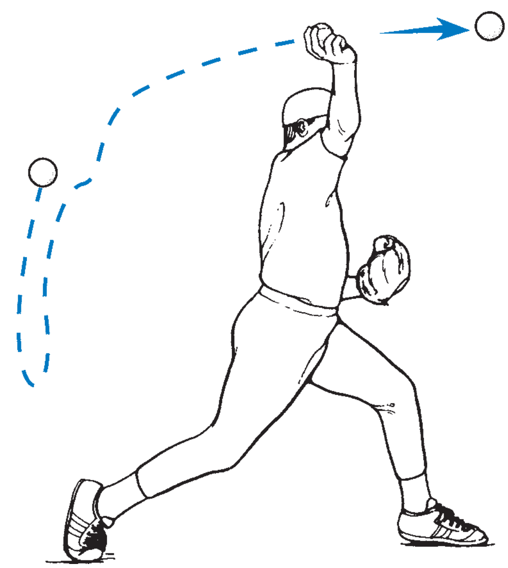


FIGURE 1-2 Examples of linear motion. Ways to apply linear motion analysis include examination of the motion of the center of gravity or the path of a projected object.

Angular motions occur about an imaginary line called the axis of rotation. Angular motion of a segment, such as the arm, occurs about an axis running through the joint. For example, lowering the body into a deep squat entails angular motion of the thigh about the hip joint, angular motion of the leg about the knee joint, and angular motion of the foot about the ankle joint. Angular motion can also occur about an axis through the center of mass.

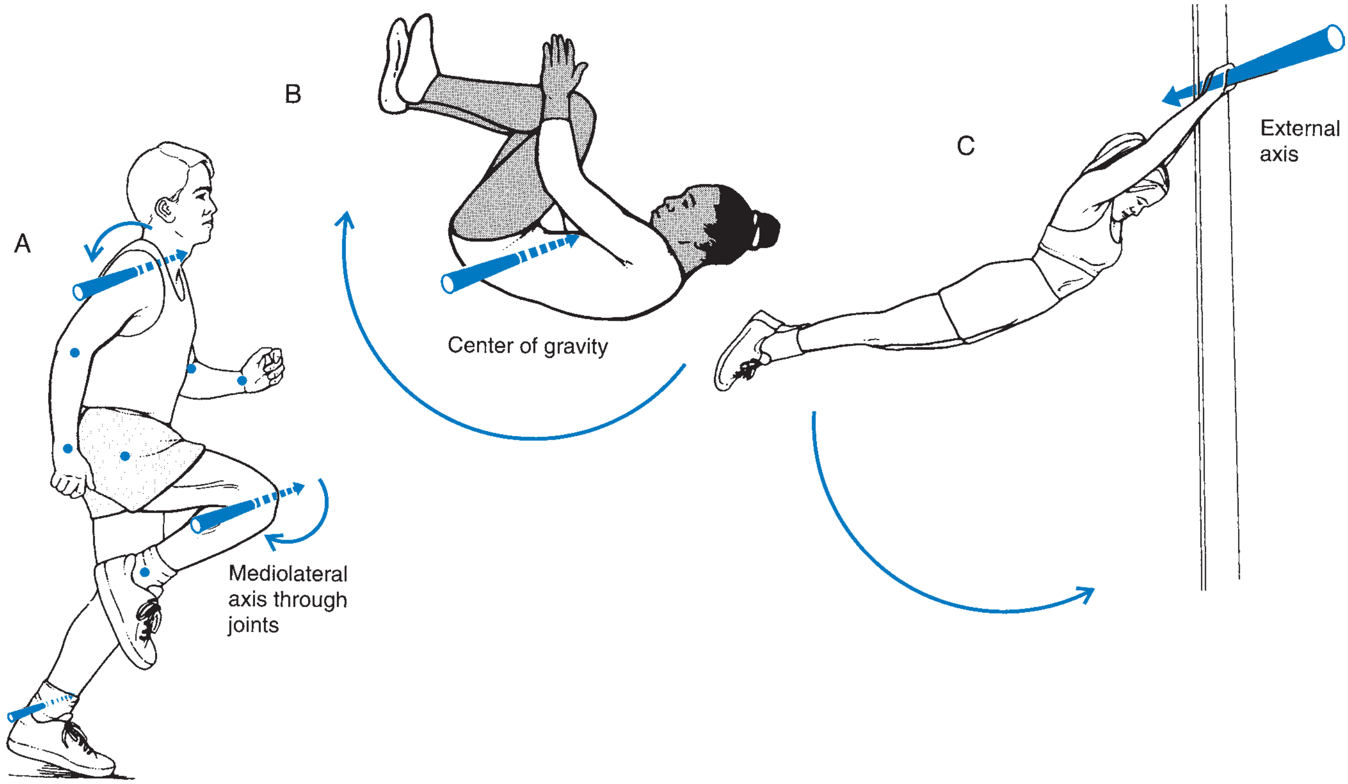


FIGURE 1-3 Examples of angular motion. Angular motion of the body, an object, or segment can take place around an axis running through a joint **(A)**, through the center of gravity **(B)**, or about an external axis **(C)**.

Examples of this type of angular motion are a somersault in the air and a figure skater's vertical spin. Finally, angular motion can occur about a fixed external axis. For example, the body follows an angular motion path when swinging around a high bar with the high bar acting as the axis of rotation.

For proficiency in human movement analysis, it is necessary to identify the angular motion contributions to the linear motion of the body or an object. This is apparent in a simple activity such as kicking a ball for maximum distance. The intent of the kick is to make contact between a foot traveling at a high linear speed and moving in the proper direction to send the ball in the desired direction. The linear motion of interest is the path and velocity of the ball after it leaves the foot. To create high speeds and the correct path, the angular motions of the segments of the kicking leg are sequential, drawing speed from each other so that the velocity of the foot is determined by the summation of the individual velocities of the connecting segments. The kicking leg moves into a preparatory phase, drawing back through angular motions of the thigh, leg, and foot. The leg whips back underneath the thigh very quickly as the thigh starts to move forward to initiate the kick. In the power phase of the kick, the thigh moves vigorously forward and rapidly extends the leg and foot forward at very fast angular speeds. As contact is made with the ball, the foot is moving very fast because the velocities of the thigh and leg have been transferred to the foot. Skilled observation of human movement allows the relationship between angular and linear motion shown in this kicking example to serve as a foundation for techniques used to correct or facilitate a movement pattern or skill.

KINEMATICS VERSUS KINETICS

A biomechanical analysis can be conducted from either of two perspectives. The first, **kinematics**, is concerned with the characteristics of motion from a spatial and temporal perspective without reference to the forces causing the motion. A kinematic analysis involves the description of movement to determine how fast an object is moving, how high it goes, or how far it travels. Thus, position, velocity, and acceleration are the components of interest in a kinematic analysis. Examples of linear kinematic analysis are the examination of the projectile characteristics of a high jumper or a study of the performance of elite swimmers. Examples of angular kinematic analysis are an observation of the joint movement sequence for a tennis serve or an examination of the segmental velocities and accelerations in a vertical jump. Figure 1-4 presents both an angular (*top*) and a linear (*bottom*) example of the kinematics of the golf swing. By examining an angular or linear movement kinematically, we can identify the segments involved in that movement that require improvement or obtain ideas and technique enhancements from elite performers or break a skill down into its component

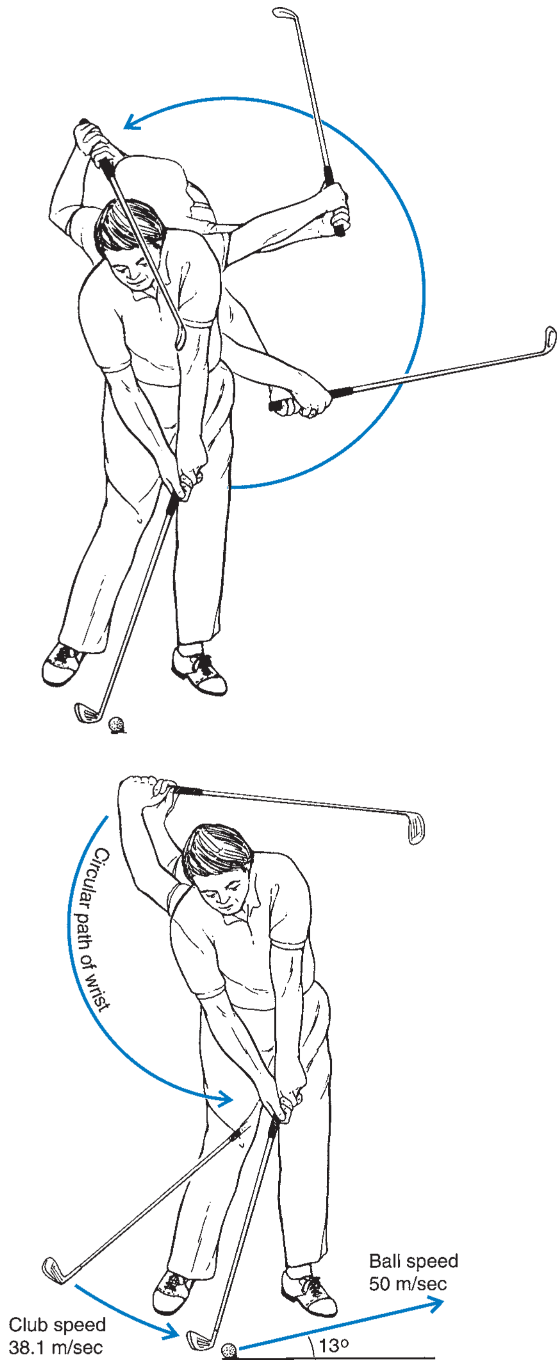


FIGURE 1-4 Examples of kinematic movement analysis. Kinematic analysis focuses on the amount and type of movement, the direction of the movement, and the speed or change in speed of the body or an object. The golf shot is presented from two of these perspectives: The angular components of the golf swing (*top*) and the direction and speed of the club and ball (*bottom*).

parts. By each of these, we can further our understanding of human movement.

Pushing on a table may or may not move the table, depending on the direction and strength of the push. A push or pull between two objects that may or may not result in motion is termed a *force*. **Kinetics** is the area of study that examines the forces acting on a system, such as the human body, or any object. A kinetic movement analysis examines the forces causing a movement. A kinetic movement analysis is more difficult than a kinematic analysis to both comprehend and evaluate because forces cannot be seen (Fig. 1-5). Only the effects of forces can be observed. Watch someone lift a 200-lb barbell in a squat. How much force has been applied?

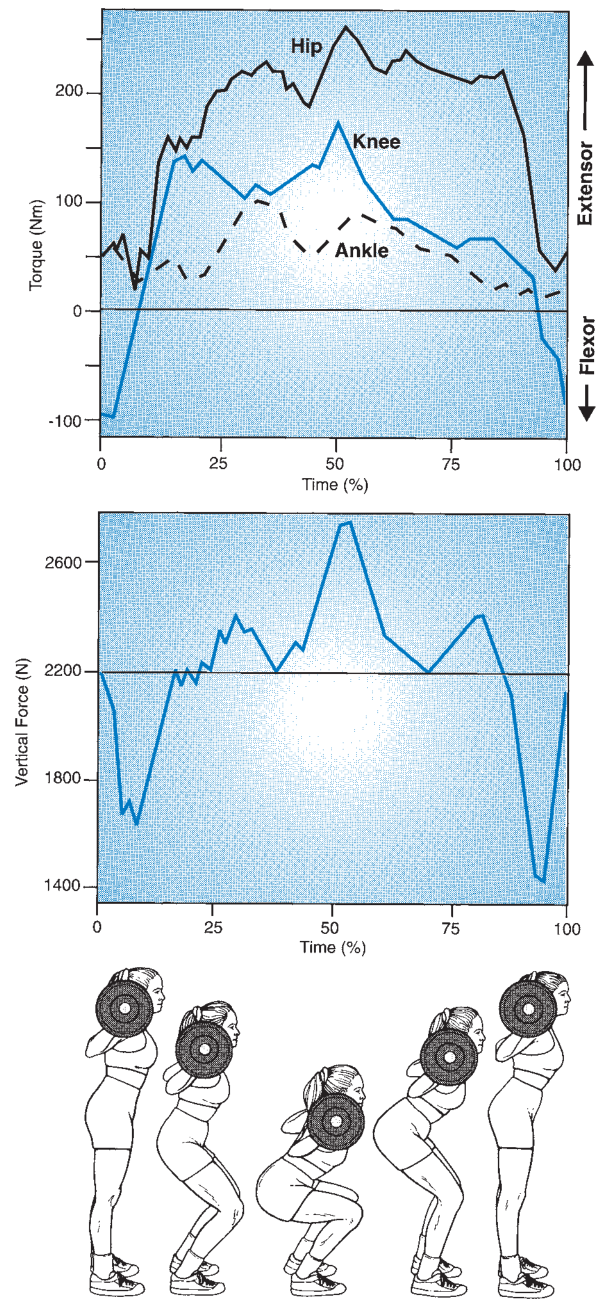


FIGURE 1-5 Examples of kinetic movement analysis. Kinetic analysis focuses on the cause of movement. The weight lifter demonstrates how lifting can be analyzed by looking at the vertical forces on the ground that produce the lift (linear) and the torques produced at the three lower extremity joints that generate the muscular force required for the lift. (Redrawn from Lander, J. et al. [1986]. Biomechanics of the squat exercise using a modified center of mass bar. *Medicine & Science in Sports & Exercise*, 18:469–478.)

Because the force cannot be seen, there is no way of accurately evaluating the force unless it can be measured with recording instruments. A likely estimate of the force is at least 200 lb because that is the weight of the bar. The estimate may be inaccurate by a significant amount if the weight of the body lifted and the speed of the bar were not considered.

The forces produced during human movement are important because they are responsible for creating all of our movements and for maintaining positions or postures having no movement. The assessment of these forces represents the greatest technical challenge in biomechanics because it requires sophisticated equipment and considerable expertise. Thus, for the novice movement analyst, concepts relating to maximizing or minimizing force production in the body will be more important than evaluating the actual forces themselves.

A kinetic analysis can provide the teacher, therapist, coach, or researcher with valuable information about how the movement is produced or how a position is maintained. This information can direct conditioning and training for a sport or movement. For example, kinetic analyses performed by researchers have identified weak and strong positions in various joint positions and movements. Thus, we know that the weakest position for starting an arm curl is with the weights hanging down and the forearm straight. If the same exercise is started with the elbow slightly bent, more weight can be lifted.

Kinetic analyses also identify the important parts of a skill in terms of movement production. For example, what is the best technique for maximizing a vertical jump? After measuring the forces produced against the ground that are used to propel the body upward, researchers have concluded that the vertical jump incorporating a very quick drop downward and stop-and-pop upward action (often called a countermovement action) produces more effective forces at the ground than a slow, deep gather jump.

Lastly, kinetics has played a crucial role in identifying aspects of a skill or movement that make the performer prone to injury. Why do 43% of participants and 76% of instructors of high-impact aerobics incur an injury (3)? The answer was clearly identified through a kinetic analysis that found forces in typical high-impact aerobic exercises to be in the magnitude of four to five times body weight (4). For an individual weighing 667.5 N (newtons) or 150 lb, repeated exposure to forces in the range of 2670 to 3337.5 N (600 to 750 lb) partially contributes to injury of the musculoskeletal system.

Examination of both the kinematic and kinetic components is essential to full understanding of all aspects of a movement. It is also important to study the kinematic and kinetic relationships because any acceleration of a limb, of an object, or of the human body is a result of a force applied at some point, at a particular time, of a given magnitude, and for a particular duration. Although it is of some use to merely describe the motion characteristics kinematically, one must also explore the kinetic sources before a thorough comprehension of a movement or skill is possible.

STATICS VERSUS DYNAMICS

Examine the posture used to sit at a desk and work at a computer. Are forces being exerted? Yes. Even though there is no movement, there are forces between the back and the chair and the foot and the ground. In addition, muscular forces are acting throughout the body to counteract gravity and keep the head and trunk erect. Forces are present without motion and are produced continuously to maintain positions and postures that do not involve movement. Principles of statics are used to evaluate the sitting posture. **Statics** is a branch of mechanics that examines systems that are not moving or are moving at a constant speed. Static systems are considered to be in equilibrium. Equilibrium is a balanced state in which there is no acceleration because the forces causing a person or object to begin moving, to speed up, or to slow down are neutralized by opposite forces that cancel them out.

Statics is also useful for determining stresses on anatomical structures in the body, identifying the magnitude of muscular forces, and identifying the magnitude of force that would result in the loss of equilibrium. How much force generated by the deltoid muscle is required to hold the arm out to the side? Why is it easier to hold an arm at the side if you lower the arm so that it is no longer perpendicular to the body? What is the effect of a lordosis (increased curvature of the back, or swayback) on forces coming through the lumbar vertebrae? These are the types of questions static analysis may answer. Because the static case involves no change in the kinematics of the system, a static analysis is usually performed using kinetic techniques to identify the forces and the site of the force applications responsible for maintaining a posture, position, or constant speed. Kinematic analyses, however, can be applied in statics to substantiate whether there is equilibrium through the absence of acceleration.

To leave the computer workstation and get up out of the chair, it is necessary to produce forces in the lower extremity and on the ground. **Dynamics** is the branch of mechanics used to evaluate this type of movement because it examines systems that are being accelerated. Dynamics uses a kinematic or kinetic approach or both to analyze movement. An analysis of the dynamics of an activity such as running may incorporate a kinematic analysis in which the linear motion of the total body and the angular motion of the segments are described. The kinematic analysis may be related to a kinetic analysis that describes forces applied to the ground and across the joints as the person runs. Because this textbook deals with numerous examples involving motion of the human or a human-propelled object, dynamics is addressed in detail in specific chapters on linear and angular kinematics and kinetics.