In This Chapter:

CHAPTER 9

How Do I Move? The Science of Biomechanics

After completing this chapter you should be able to:

- describe the effects of mass, gravity, and inertia on human motion;
- distinguish between different types and causes of human motion;
- identify Newton's laws of motion and describe practical illustrations of the laws;
- explain the role of friction in the context of fluid dynamics;
- discuss the factors affecting balance and stability in human performance;
- evaluate qualitative analyses of human motion.

The capabilities of the human body seem endless. From a baby's first step, to an Olympic performance, we marvel at the wide range of human movements that are possible. We have all witnessed the powerful gymnast who explodes off the floor to perform three rotations in the air before landing on his or her feet, or the diver who twists and turns in the air before entering the water with delicate precision. But what causes these movements? How do we describe them? Are there limitations to what we can do? The science of biomechanics provides answers to these questions.

Biomechanics is considered a relatively young field of scientific inquiry. Nevertheless, research involving biomechanics is extremely diverse and multifaceted (Figure 9.1). It tries to describe the causes and effects of how the body moves; it examines the internal and external forces acting on the human body and the effects produced by these forces; and it allows us to understand why humans walk the way we do and what effect gravity has on the human musculoskeletal system. Sport biomechanists have also contributed invaluably to improving performances in selected sports, such as wheel and helmet designs for cycling, optimal body positioning for ski jumping during the flight phase, and the most effective technique for throwing a discus or baseball.

Biomechanics has significantly added to our knowledge of human movement, from analyzing technique to developing innovative equipment designs. Understanding the mechanical principles that underlie human movement can help answer questions related to human health and performance. This chapter will provide you with the foundation necessary to identify, analyze, and effectively answer questions related to the biomechanics of human movement.

Types of Study

Quantitative Versus Qualitative Analysis

Biomechanists spend a great deal of time devising techniques to measure those biomechanical variables that are believed to optimize performance. These scientists may investigate the pattern of forces exerted by the foot onto the sprinter's starting block, the sequence of muscle activity during running, or the three-dimensional movements of each body segment during a high jump. To collect numeric measurements of performance in these studies, biomechanists use high-tech instrumentation, such as computerized force-measuring platforms, electromyography, and high-speed video recording systems, and perform motion analyses via computerized video-digitizing. These are examples of the **quantitative analysis** of human performance intended for use by researchers, which will be left for further study (see box *Measurement Technology in Practice*).

Coaches and teachers do not always have available to them the necessary equipment or the knowledge to perform these complex analyses and

Figure 9.1 Although biomechanics is considered a relatively young field of study, it has contributed significantly to our knowledge of human movement, from analyzing technique to developing innovative equipment designs.

Measurement Technology in Practice

Electromyography

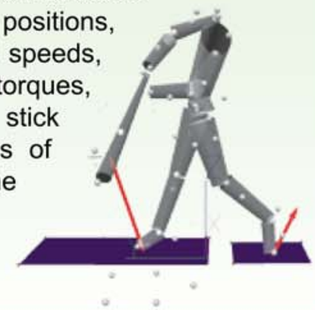
Electromyography (EMG) measures and records the electrical activity generated by the muscles as they are stimulated by the athlete's nervous system. In this procedure the electrodes are placed either on the skin (surface EMG) or directly into the muscle (indwelling EMG). The system records the electrical processes of the contracting muscles and determines their timing (onset and duration of the contraction) during performance.

Force Platforms

Force platforms measure the forces generated on the ground by athletes performing athletic skills using special computerized biomechanical instruments. The devices are firmly secured to the floor to eliminate any vibrations. As an athlete stands, lands, or steps on the platform during a skilled performance, three-dimensional (3-D) force data are generated that reveal forces in the vertical, anteroposterior, and mediolateral directions. Force–time graphs are created that enable the biomechanist to analyze force patterns generated by the athlete and reveal performance faults.

Computerized Motion Analysis

Computerized motion analysis systems allow multiple forms of biomechanical instrumentation to be synchronized for more sophisticated collection of data from athletic performance. The system generates synchronized data related to the athlete's body positions, joint angles, movement speeds, accelerations, forces, torques, and so on. Animated stick figures and 3-D models of the athlete's body are the most common results of these investigations.



thus must rely on any information they can readily obtain, visual or aural, to assess performance. This type of analysis is known as a **qualitative analysis**. A qualitative analysis requires a framework within which skilled performances can be observed, a set of principles within which movement can be analyzed, a checklist to use when identifying errors, and techniques to use to correct errors in performance. The coach observes the performance and, through an understanding of the skill and basic concepts of biomechanics, offers to the athlete an opinion on how improvements in performance can be accomplished. The athlete then attempts to follow these instructions. The qualitative analysis of human motion is presented as the last topic of this chapter.

Kinematics Versus Kinetics

The study of **kinematics** describes spatial and timing characteristics of motion of the human body and its segments without reference to the forces that cause the motion. These variables are used to describe both linear and angular motion, and they answer four questions: how long? how far? how fast? and how consistent was the motion? Kinematic variables include measurements of time, velocity, displacement, and acceleration.

Kinetics, on the other hand, focuses on the various forces that cause a movement: that is, the forces that produce the movement and the resulting motion. These forces can be internal or external. **Internal forces** refer to forces generated by muscles pulling on bones via their tendons, and to bone-on-bone forces exerted across joint surfaces. **External forces** on the body refer to those forces acting from without, such as the force of gravity, or the force from any body contact with the ground, environment, sport equipment, or opponent.

Quantifying the various forces applied on or by a system enables the biomechanist to determine why a body moves the way it does. This information may lead to a detailed analysis of movement mechanics because these forces lead directly to acceleration, which, in turn, leads to changes in body position.

Models of Human Motion

Biomechanics is a science that examines the internal and external forces acting on the human body and the effects produced by these forces. All body tissues undergo shape deformations during sport movements and most sports skills occur in three dimensions, which adds a great deal of complexity to understanding and observing human movements. To make the study of human movement possible, biomechanists have adopted three simplified models of human motion analysis: the particle, stick figure, and rigid body segment models (Figure 9.2).

Particle Model The **particle model** is a simple dot representing the center of mass of the body or object (see box *Center of Mass*). Particle models are used when the human body or object is airborne and in flight. In sport, these include any ball or object that is thrown, struck, hit, or kicked, as well as the human body in flight such as during diving, high jumping, or tumbling. In all of these examples, the object or body is said to be a projectile.

Stick Figure Model The **stick figure model** is used to represent athletes who are in contact with the ground or other earthbound objects (e.g., diving board, starting block). Body segments are represented by rigid bars (sticks) linked together at the joints. Stick figures indicate approximate body segment positions, their connections, and their size. External forces can be shown acting on the stick figure at the appropriate locations. Stick figure models are used to represent the total body configuration for gross motor skills that occur in two dimensions. Sprint starts, running, and somersaults are good examples. They cannot easily represent small or fine local muscle movements (such as the grip on a baseball) or longitudinal rotations.

Rigid Body Segment Model For most sophisticated three-dimensional (3-D) analyses, biomechanists employ a **rigid body segment model** in which each body segment is represented as an irregularly shaped 3-D volume. The shape deformation of body segments during vigorous activity adds to the complexity of these analyses. Sophisticated computer motion analyses systems are used for this type of analysis (see box *Measurement Technology in Practice* on the previous page).

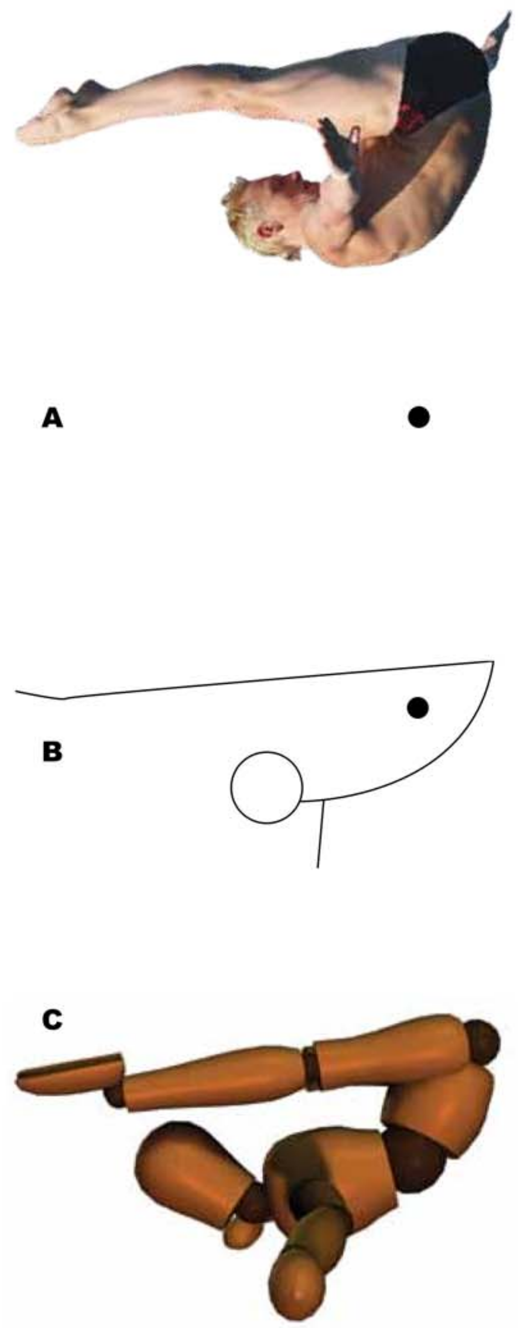
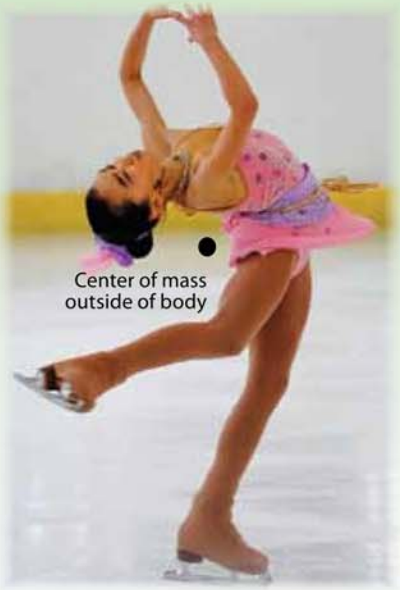


Figure 9.2 Three simplified models of human motion can be used to represent the diver pictured below. **A.** Particle model. **B.** Stick figure model. **C.** Rigid body segment model.

Center of Mass

The point around which the body's mass is equally distributed in all directions is known as the **center of mass**, or **center of gravity** (CG). The CG of a perfectly symmetrical object of homogeneous density is at the exact center of the object. For example, the CG of a bowling ball or golf ball is at its geometric center. If the object is a homogeneous ring (such as a ringette ring), the CG is located in the hollow center of the ring.

However, your center of mass is not always found inside the body (as in the case of the figure skater). In general it is located about 6 inches above the groin area at approximately 55 percent of standing height in females and 57 percent in males, which means females generally have a lower center of gravity than males.



The location of the CG in the human body is of interest because a body behaves as though all of its mass were concentrated at the CG. Therefore, the force of gravity acting on this point of mass would be the same as the force of gravity acting on the total body. Or when the human body acts as a projectile, as in a long jump, the body's CG follows a parabolic trajectory, regardless of what the various segments of the body do while in the air.

Motion Concepts

Types of Motion

Human movement is composed of a number of fundamental types of motion. We differentiate between linear, angular, and general motion.

Linear Motion

Linear motion occurs when all parts of the body move the same distance, in the same direction, and at the same time, such as a toboggan run, a skater's glide, or a sprinter. Another term often used for linear motion is **translation**, which refers to movement of the body as a unit without individual segment parts of the body moving in relation to one another.

Movements in a linear fashion may be along a straight line (rectilinear), such as a sprinter's 100-meter dash or a dropped ball, or a curved line (curvilinear), such as a ski jumper's flight, a thrown discus, or a batted baseball.

Angular Motion

When a body moves on a circular path and in the same direction, then the body is experiencing **angular motion**, or **rotation**. The line about which bodies rotate is called the axis of rotation. A good example of this type of motion is a gymnast executing giant swings on a high bar.

Body segments also experience angular motion about their joints as they flex, extend, and longitudinally rotate. Twisting somersault dives, the shot put, and an automobile's wheels turning around their axes are good examples of angular motion.

General Motion

A combination of linear and angular motion (i.e., body moving linearly and rotating simultaneously) is referred to as **general motion**. This is true for most athletic and many everyday activities (e.g., gymnastics floor routine, wrestling, a diver falling downward while simultaneously rotating in a somersault).

Mass, Gravity, and Inertia

All objects have matter. The measure of how much matter an object has is its **mass**. Because objects have mass, they are also reluctant to change whatever they are doing. In other words, they are reluctant to change their state of motion from rest to motion, or to moving faster or slower, or to slowing down to rest. This property of objects is called **inertia**. Compared to a soccer ball, a tennis ball has less mass and therefore less inertia. If both are on the ground and have no motion, which ball would be easier to kick and therefore change its state of motion? If both were traveling at the same velocity, which one would you rather stop (i.e., change its state of motion from moving to rest)?

Terminology Alert

Gravity is the force of attraction between two bodies, the magnitude of which is proportional to their masses and inversely proportional to the square of the distance between them.

Weight Versus Mass

There is a difference between mass (m) and weight (W). **Mass** is a measure of inertia, while **weight** is a measure of the force of **gravity** (g) acting on the body. Mass is measured in kilograms (kg), while weight is measured in Newtons (N). A person's weight varies directly with the magnitude of the acceleration due to gravity (9.8 m/s^2).

$$W = m \times g$$

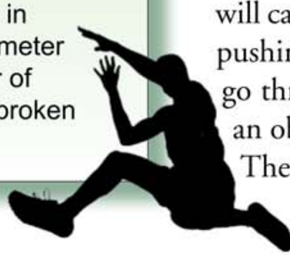
Thus in space where there is no acceleration experienced due to gravity we weigh 0 N but have the same mass as we do on earth.

Rotating objects also have a reluctance to change their state of angular motion: from rest to rotation, or to rotating faster or slower, or to slowing down back to rest. The inertia of rotating objects is measured by their **moment of inertia**, and it depends on their mass and how their mass is distributed about their axis of rotation. It is more difficult to change the state of rotation of a soccer ball, compared to a tennis ball, because it is more massive and its mass is found farther away from any axis of rotation (i.e., the diameter of the soccer ball is larger). Similarly, a layout dive is harder to perform than the same dive in the tuck position because the athlete's body parts are farther away from the rotating axis (which passes through the athlete's center of mass), giving the layout diver a greater moment of inertia.

Did You Know?

For sporting activities (anywhere except outer space) gravity represents a force of attraction between the masses of the athlete and the earth, which varies in magnitude according to the location on the earth. The closer the athlete is to the center of the earth (polar regions, sea level) the greater the force of attraction. The farther the athlete is from the center of the earth (equator, mountains) the less the force of attraction.

At the 1968 Olympic Games, Bob Beamon jumped longer than any other human in the history of track and field. His 8.9-meter jump (just over 29 feet) in the light air of 7,349-foot-high Mexico City was not broken until two decades later.



Causes of Motion

As discussed earlier in the chapter, the cause of motion of the human body is the application of forces, which can be internal or external. A **force** is any action, a push or pull, that tends to cause an object to change its state of motion by experiencing acceleration. If an object is not accelerating, then it experiences a state of constant velocity (note: rest or no motion is just the state of constant "zero" velocity).

Forces that act through a body's center of mass will cause linear motion, such as throwing a ball or pushing a cart (Figure 9.3 A). Forces that do not go through the center of mass, or pivot point, of an object cause motion about an axis of rotation. These actions cause the object to change its state

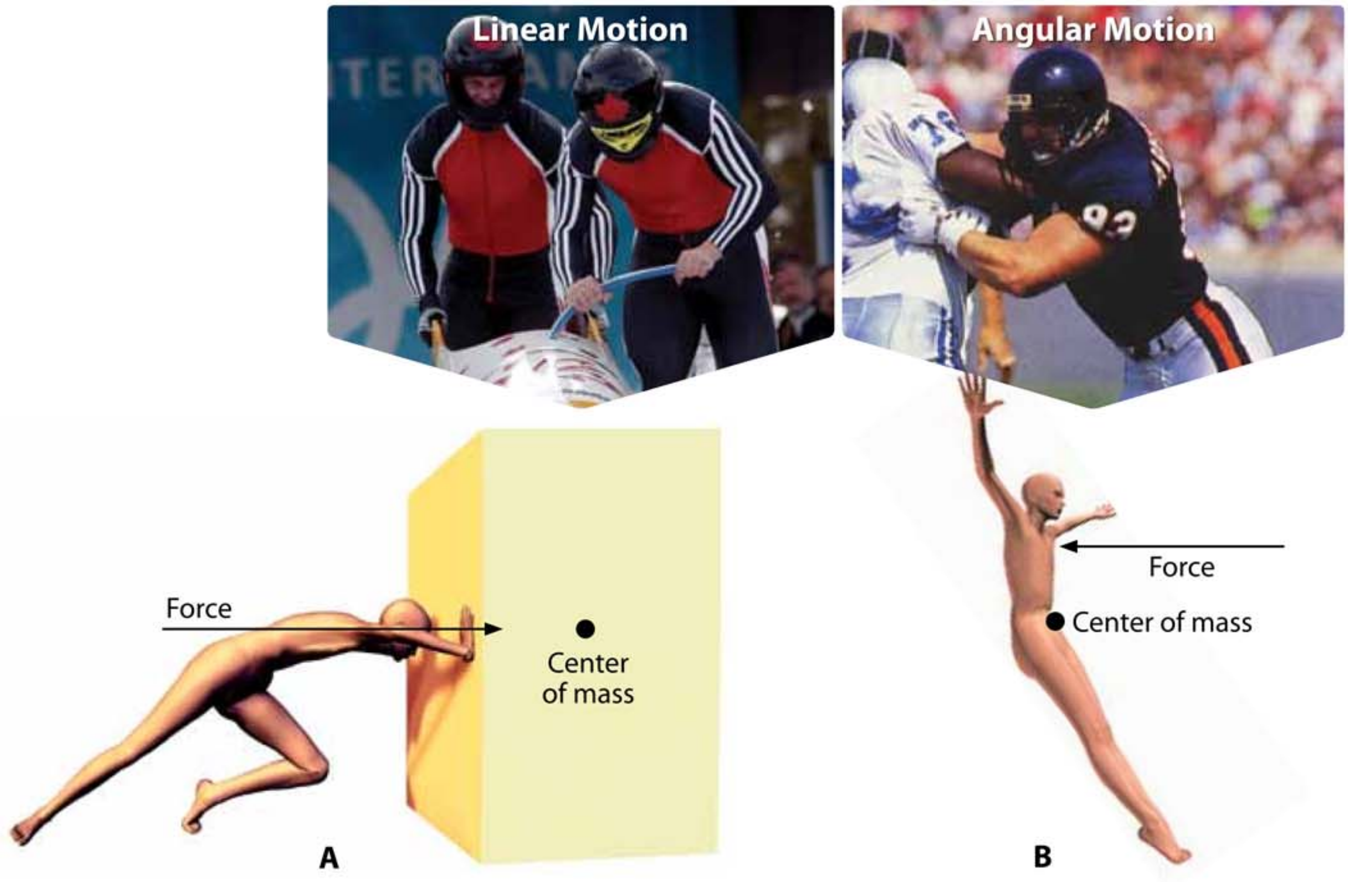


Figure 9.3 Causes of linear and angular motions. **A.** Linear motion results when the forces are applied through the center of mass. **B.** Angular motion results when forces are applied away from the center of mass.

of angular motion by experiencing an angular acceleration. When a force causes angular motion the effect is known as a **moment of force**, or **torque**. Torque is generated to open a door, flex a joint, or move an opponent (Figure 9.3 B). This concept is discussed further in the section on levers.

Angular Kinetics

Angular kinetics is concerned with the generation of rotations about an axis of rotation and the control of these rotations. All objects possess inertia and do not wish to start rotating, or if rotating, to change the quantity of rotation they have. However, if an external moment of force is applied to the object, then it will experience an angular acceleration, which results in a new state of motion (Figure 9.3). The greater the applied moment of force (action), the greater the change in the angular acceleration (reaction).

The somersault serves as a good example of angular kinetics. It is found extensively in diving, freestyle skiing, and gymnastics. For all these skills, the somersaulting motion is generated while the athlete is on the ground.

Off-center External Forces Any external force that acts away from the body's center of mass will create a moment of force acting on the total body. This is so because all bodies, when airborne, rotate about an axis passing through their center of mass. Usually the off-center force is a reaction force from the ground or equipment (e.g., diving board), resulting from the internal muscle forces generated by the athlete.

However, if an athlete has forward momentum (e.g., running) and a pivot point is created, then some or all of the linear motion can be transferred