




How Do I Move? The Science of Biomechanics

After completing this chapter you should be able to:

- distinguish between different types and causes of human motion;
- identify Newton's laws of motion and describe practical illustrations of the laws;
- describe the expected path and motion of a projectile;
- describe the conservation of momentum within the body, and explain why changes in the configuration of a rotating airborne body produce changes in its angular velocity;
- explain the role of friction in the context of fluid dynamics;
- 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? Biomechanics, one of the biophysical sciences that make up the field of physical and health education, tries to describe the causes and effects of how the body moves.

Biomechanics is a science that examines the internal and external forces acting on the human body and the effects produced by these forces. It is considered a relatively young field of scientific inquiry, but many other scientific disciplines and professional fields make use of biomechanical considerations. People in various walks of life, including physical and health education, use the principles of biomechanics. Academic backgrounds in fields such as sports medicine, physical therapy, kinesiology, biomechanical engineering, and even zoology can offer important knowledge to the biomechanical aspects of the structure and function of living things.

For example, biomechanics allows us to understand why humans walk the way we do, what effect gravity has on the human musculoskeletal system, how mobility impairment in the elderly can be improved, and how a prosthesis can aid individuals with below-knee amputations. These are real concerns that can have a significant impact on the lives of many people. Sport biomechanists and engineers have also contributed invaluable 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. Have you ever wondered why some golfers tend to slice the ball, or why pole-vaulting records have continued to fall since the introduction of fiberglass poles?

From playing surfaces and equipment to shoes, biomechanics plays an important role in recognizing what practices are perhaps less effective and less dangerous and how athletes optimize performance. Research continues to be conducted in an attempt to highlight these concerns and provide more effective alternatives.

Obviously, research involving biomechanics is extremely diverse and multifaceted. From analyzing technique to developing innovative equipment designs, biomechanics has significantly added to our knowledge of human movement. Before the advent of fiberglass poles, clearing a height of 20 feet (6 meters) in pole vaulting would have seemed unreachable. 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 (1) the pattern of forces exerted by the foot onto the sprinter's starting block; (2) the sequence of muscle activity during running using electromyography; or (3) the three-dimensional movements of each body segment during a high jump using high-speed cinematography or an automated motion analyzing system. These studies are examples of **quantitative analyses** of performance. A quantitative analysis is intended for use by researchers and will be left for further study.

Coaches and teachers do not always have available to them the necessary equipment to perform these analyses and thus must rely on



Figure 8.1 Biomechanics can help us understand sport performances by suggesting better teaching and coaching techniques (A), comparing different techniques for performing the same skill (B), and improving error detection and correction techniques (C, D).

Kinematic Variables

Time

How long does it take to run a race, to swing a bat, to perform a karate chop, or to prepare to jump in volleyball? How long is a diver airborne before entering the water? *How long* refers to the temporal characteristics of a performance, either of the total skill or of its phases. It is a time interval calculated as the difference between the beginning and end of two instants of time.

Displacement

Displacement is the **length** and **direction** of the path an athlete traverses from the start to finish of a performance or portion thereof. Sprinters run 100 meters east. Volleyball players jump 0.8 meters up during a block.

Angular Displacement

Angular displacement measures the direction of and **smallest angular change** between the rotating body's initial and final position. In standing up from a chair, the knee joint and hip joint both rotate through approximately 90 degrees but in opposite directions (i.e., clockwise and counterclockwise). A diver performing a front 1½ dive would have an angular displacement of 180 degrees clockwise or counterclockwise.

Velocity

Velocity is the measure of the displacement per unit time. Velocities can be calculated as instantaneous (i.e., occurring over a very small time interval) or as average, where the time

interval is longer (i.e., the time it takes to run a complete race). The top sprinters in the world, such as Usain Bolt of Jamaica, have reached peak velocities over 12 m/s and average velocities over 10 m/s (e.g., $100 \text{ m} / 9.58 \text{ s} = 10.44 \text{ m/s}$) in competition.

Angular Velocity

Angular velocity is the measure of angular displacement per unit time, or how fast a body is rotating. The rotation of the arm about the shoulder joint during the delivery swing of a bowling ball has a lower angular velocity than the same movement in a fastball pitcher.

Acceleration

Acceleration is the rate of change of velocity. Success in many sports activities depends upon the athlete's ability to increase or decrease speed and/or direction rapidly, such as changes of direction in basketball or football, or stealing a base in baseball, or sprinting a 100-meter dash, or throwing a shot, or decreasing the velocity of a ball when catching in handball.

Angular Acceleration

Angular acceleration is the measure of change in angular velocity per unit time. During a giant swing, a gymnast begins from a handstand and swings once around the bar. The gymnast accelerates clockwise on the way down but experiences deceleration clockwise during the up phase.

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. Good qualitative analyses lead to good quantitative analyses.

Whether they are working with developing

or advanced athletes, biomechanists can provide coaches and instructors with (1) knowledge on how a skill is done; (2) a basis for the comparison of techniques; (3) better teaching and coaching techniques; and (4) improved ability to detect and correct errors in performance (Figure 8.1).

Kinematics Versus Kinetics

The study of **kinematics** describes spatial and timing characteristics of motion of the human



body and its segments. These variables are used to describe both linear and angular motion (see box *Kinematic Variables*). They answer four questions: how long? how far? how fast? and how consistent was the motion?

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. The forces, which act on the human body, 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. In general, internal forces *cause* individual body segment movements, while external forces *affect* total body movements.

Biomechanical Models of Human Motion

Biomechanics has been defined as the science that examines the internal and external forces acting on the human body and the effects produced by these forces. For example, a hockey player skating down the ice is generating internal forces in the leg muscles during each skating stroke. The net result of all of these internal muscle forces is a sequence of pushes against the ice with the skate blade. With each push against the ice, the ice pushes back upon the hockey player (note: the ice is an external force), and as a result the skater experiences forward movement. Other external forces also act upon the skater such as gravity, the weight of the hockey stick, or an opposing player who gives the skater a body check into the boards. Each of these external forces in turn has an effect upon the motion of the human body. A body check, for example, causes the hockey player to crash into the boards.

While we can visualize the hockey player crashing into the boards, the actual human body with all its bones, muscles, connective tissue, and internal organs is too complex for most biomechanical analyses. Anatomical differences exist between people due to race, age, sex, health, and lifestyle. Furthermore, all body tissues undergo shape deformations during sport movements. Moreover, the human body is multisegmented, such that the same total body or limb movement can be performed using different segment movement sequences. And finally, 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, biomechanics has adopted three simplified models of human motion analysis: the particle, stick figure, and rigid segment body models.

The Particle Model

The **particle model** is a simple dot representing the center of mass (see box *Center of Mass*, page 173) of the body or object (Figure 8.2 A). Particle models are used when the human body or object is airborne and in flight. When the body is airborne it is already free from its surroundings. Most often, gravity (see box *Gravity*, page 174) is the only external force acting on the body through its center of mass. For objects that possess a relatively large velocity, such as baseballs, javelins, and discs, the surrounding air will also apply a force to the object (see Figure 8.13, page 181). This external force, known as air resistance, will also affect the motion of the object.

Since particle models involve only the center of mass of an object, they are limited to bodies 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.

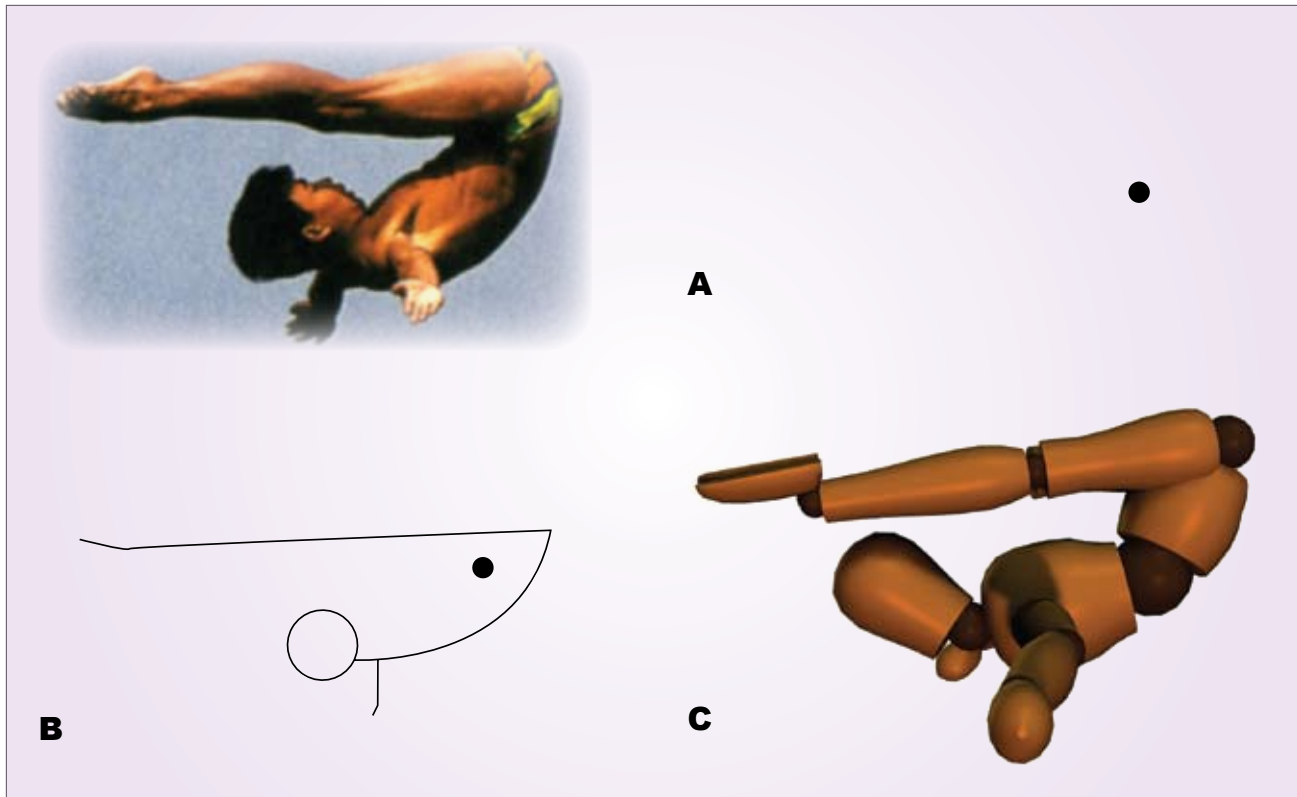


Figure 8.2 Three models used to represent the diver pictured above. **A.** Particle model. **B.** Stick figure model. **C.** Rigid segment body model. Choice of model is based on the type of biomechanical analysis to be made.

The Stick Figure Model

For athletes who are in contact with the ground or other earth-bound objects (e.g., diving board) a **stick figure model** is used to represent their bodies (Figure 8.2 B). Body segments are represented by rigid bars (sticks) linked together at the joints. Stick figures indicate approximate body segment positions, their connections, and size. External forces, represented by vectors, 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. Nor can they represent longitudinal rotations, either total body twisting movements or segment rotations such as pronations. Total body skills, which occur with

many three-dimensional movements, are also difficult to draw.

A sequence of stick figures representing either the total body or portion thereof is known as a **composite diagram** (Figure 8.3). Composite diagrams give a quick picture of the body actions involved in a skill. To our mind's eye, they resemble our visual impression of a skill. However, because the stick figure links have no volume, the stick figure cannot be truly individualized to the athlete.

The advantage of the stick figure over the particle model is that multiple force vectors can be drawn on the free body diagram. These vectors can represent gravity or air resistance forces acting at the center of mass and reaction forces (described later in the chapter) acting on the body wherever contact is made with the environment. Some of these forces may create moments of force and thus indicate rotation of the body or its segment parts

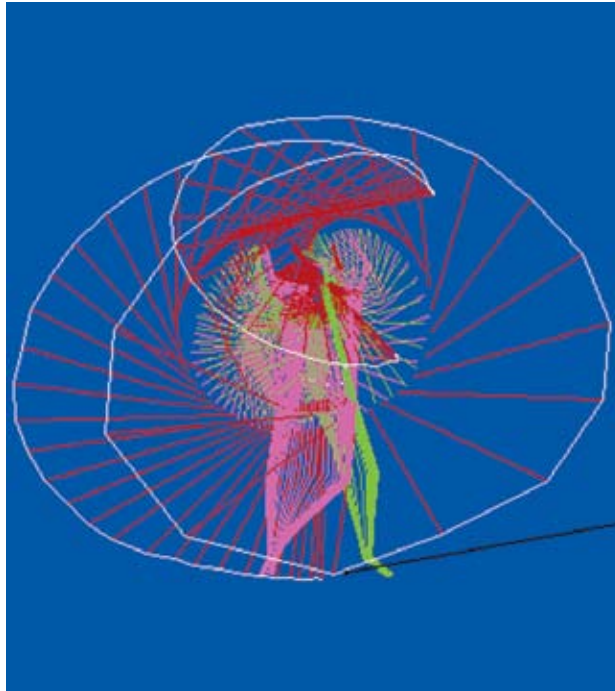


Figure 8.3 Composite diagrams provide a pictorial overview of the performance. However, if the motion does not occur in the two-dimensional plane of the diagram, then accurate measurements, such as angular velocity of the golf club, will be difficult.

(Figure 8.9, page 172).

The Rigid Segment Body Model

For sophisticated three-dimensional (3D) analyses, biomechanists employ a **rigid body segment model** in which each body segment is represented as an irregularly shaped 3D volume (Figure 8.2 C). The shape deformation of body segments during vigorous activity adds to the complexity of these analyses.

Steps of Analysis

There are three preliminary steps that must be completed before any human or object motion can be described using the three biomechanical models.

Step 1

Identify the system to be studied: in other words, isolate the object of analysis from its surroundings (e.g., arm, leg, tennis racket, or total body of a runner) (Figure 8.4).

Step 2

Identify the frame of reference (or coordinate system) in which the movement takes place (e.g., a runner changes his position relative to the ground and to some starting point; Figure 8.4). While many sport movements are usually described as occurring in two dimensions (running, somersaulting), most sport activities (or components) actually occur in three dimensions.

Step 3

Identify the type of motion that is occurring, the **body planes** in which movement takes place (sagittal, frontal, and transverse, see Chapter 2), and the **axes of rotation** about which rotational motion occurs (either through a joint or the total body).

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 (Figure 8.5 A). 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.

Rectilinear motion occurs when the movement follows a straight line (a 100-meter sprinter's movement); a **curvilinear motion** occurs when the

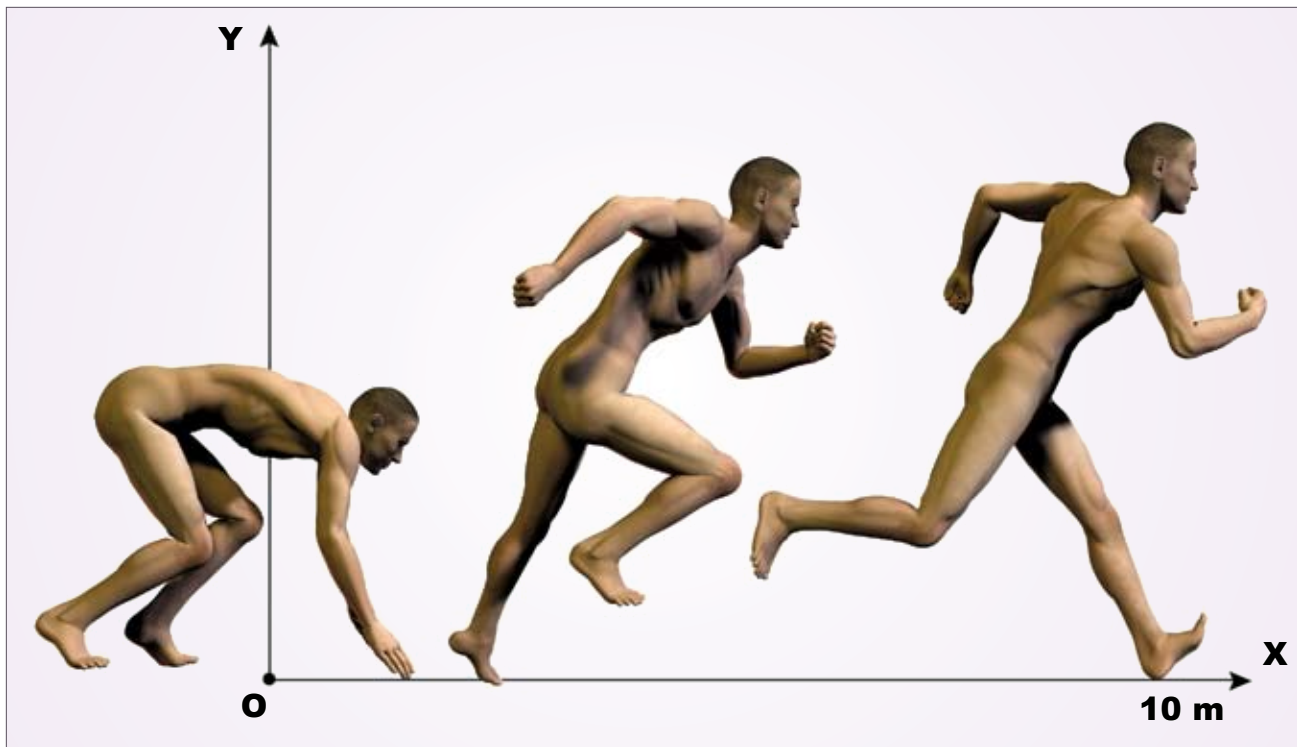


Figure 8.4 Identifying the system and reference frame. The system is the total body of a runner. The reference frame is the two-dimensional xy plane, with the origin at the start line.

movement path is curved (a ski jumper's flight).

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 (Figure 8.5 B).

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; Figure 8.5 C).

Causes of Motion

The cause of motion of the human body is the application of internal and external forces. 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).

There are two types of motion resulting from the application of a force, linear motion and angular motion. Forces that act through a body's center of mass will cause linear motion, such as