МЕДИЦИНСКИ УНИВЕРСИТЕТ – ПЛЕВЕН

ФАКУЛТЕТ „ОБЩЕСТВЕНО ЗДРАВЕ“

ЦЕНТЪР ЗА ДИСТАНЦИОННО ОБУЧЕНИЕ

Лекция №1

БИОМЕХАНИКА

Увод в механиката. Движение и деформации на телата. Кинематика, динамика, статика. Класическа механика и биомеханика. Механика на твърдите тела и флуидите. Механика на твърдите тела. Механични термини и понятия: пространство и време, абсолютно твърдо тяло, материална точка. Скаларни и векторни величини. Действия с вектори.

Проф. Константин Балашев, дхн

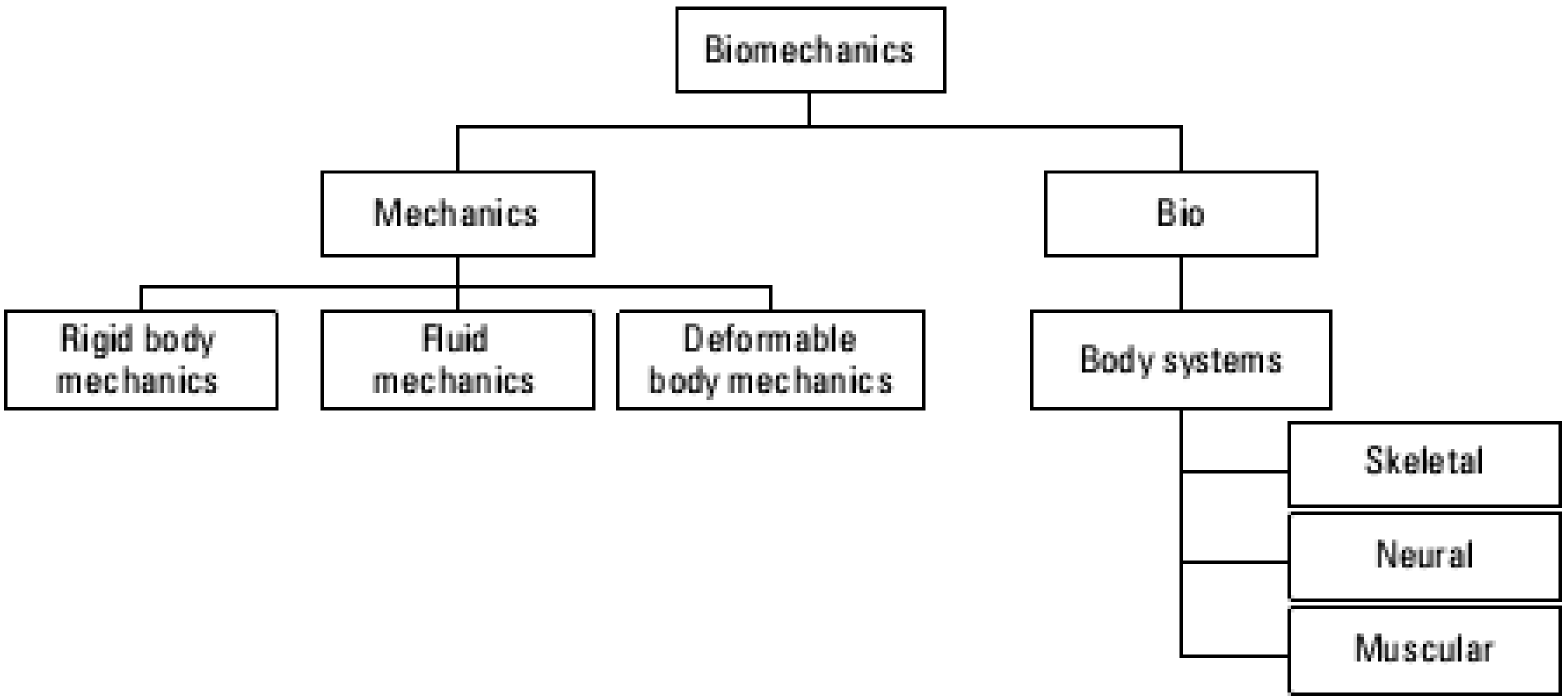


Figure 1-1: The branches of bio-mechanics.

Mechanics

Mechanics is a long-established field of study in the area of physics. It focuses on the effect of forces acting on a body. A *force* is basically a push or a pull applied to a body that wants to make it move (see Chapter 4). Mechanics looks at how a body is affected by forces applied by muscle, gravity, and contact with other bodies.

Rigid body mechanics

An applied force affects the motion of a body — meaning, it tries to make the body speed up or slow down. The motion can be large and involve a lot of body segments, like walking, or it can be small and involve only a couple of segments, like bending a finger. Both of these movements, and all other movements involving body segments, can be analyzed using rigid body mechanics.

Rigid body mechanics simplifies a body by *modeling* (representing) it as a single, rigid bar. A rigid bar can be used to represent the entire body (quite a simplification) or just the individual segments of the body. The modeled segments can be combined as rigid, non-deforming links joined at hinges (the joints) to represent any part of the body.

Fluid mechanics

Fluid mechanics is the branch of mechanics focused on the forces applied to a body moving in air or water. These fluids produce forces called *lift* and *drag*, which affect the motion of a body when a fluid moves over it, or as the body moves through a fluid.

Fluid mechanics is obviously applicable to swimming and water sports, but it's also useful when explaining how to make a soccer ball, tennis ball, or baseball curve through the air. For more on fluid mechanics, float on over to Chapter 11.

Deformable body mechanics

Deformable body mechanics focuses on the changes in the shape of the body that are ignored in rigid body mechanics. An applied force causes a *deformation* (change in shape) of the body by loading the particles of material making up the body. Deformable body mechanics involves looking at the loading and the motion of the material within the body itself.

The loading applied to a body is called a *stress*. The size and the direction of the stress cause deformations of the material within the body, called *strain*. The relationship between the applied stress and the resulting strain is useful to understand injury to and training of tissues within the body. Chapter 12 provides more detail on deformable body mechanics.

Bio

Bio is Greek for "life," making biomechanics the science applying the principles of mechanics to a living body. Biomechanics is used to study and explain how and why living things move as they do, including the flight of a bumblebee, the swaying of a stalk of corn, and, more important for most of us, the movements of human beings.

- **Skeletal system:** The skeletal system, including bones, ligaments, and joints, provides the physical structure of the body and allows for movement. (See Chapter 13.)
- **Neural system:** The neural system, also known as the nervous system, including different types of nerve cells, serves as the communication system to control and respond to movement. (See Chapter 14.)
- **Muscular system:** The muscular system, including muscle and the tendon attaching muscle to bone, provides the motors we control to make our segments, and our bodies, move. (See Chapter 15.)

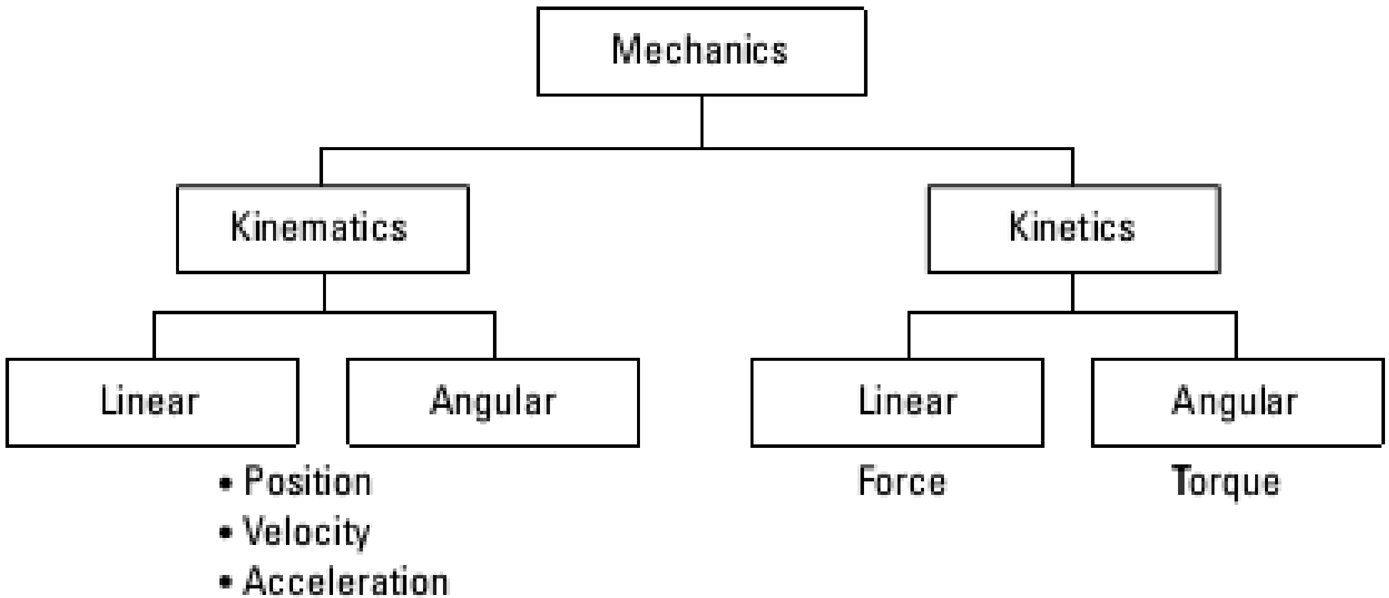


Figure 1-2: The subdivisions of mechanics.

Describing motion with kinematics

Kinematics is the subdivision of mechanics focused on the description of motion. Kinematics is what we see happen to the body. When you watch a body, and describe its position, how far it travels, how fast it travels, and whether it's speeding up or slowing down, you're conducting a kinematic analysis.

Linear kinematics

Linear kinematics describes *linear motion*, or motion along a line (also called *translation*). There are two forms of linear motion:

- **Rectilinear motion:** Translation in a straight line. Your fingertip exhibited rectilinear motion as you successfully traced a line across the page or screen.
- **Curvilinear motion:** Translation along a curved line. Your fingertip exhibited curvilinear motion when you tried to move it across the page using only a single joint.

- *Distance* and *displacement* are often used interchangeably to describe how far a body moves, but in mechanics *distance* simply means how far and *displacement* means how far in a specified direction.
- *Speed* and *velocity* both describe how fast a body moves, but in mechanics *speed* is simply how fast a body moves, while *velocity* refers to how fast the body moves in a specific direction.
- *Acceleration* is a tricky, but important, idea describing a change in velocity of a body. In everyday language, *acceleration* is often used to mean "speeding up" and *deceleration* is often used to mean "slowing down." In mechanics, *acceleration* is used to describe both speeding up *and* slowing down. The term is used both ways because acceleration provides a link between the description of motion, kinematics, and the force causing the motion, *kinetics*. For example, the force of gravity creates a downward acceleration on a body; when you jump into the air, the downward acceleration of gravity slows down your upward motion when you're going up, but speeds up your downward motion when you're coming down.

- ✔ *Angular distance* and *angular displacement* describe how far a body rotates. Similar to linear kinematics, *angular distance* means how far the body rotates, while *angular displacement* means how far it rotates in a specified direction.

Causing motion with kinetics

Kinetics is the subdivision of mechanics focused on the forces that act on a body to cause motion. Basically, a *force* is a push or a pull exerted by one body on another body. But a force, whether it's a push or a pull, can't be seen — we can see only the *effect* of a force on a body. An applied force wants to change the motion of the body — to speed it up or slow it down in the direction the force is applied. As I describe earlier, the speeding up or slowing down of a body is called *acceleration*.

Sir Isaac Newton formulated a set of three laws, appropriately called Newton's laws, describing the cause–effect relationship between the force applied and the changing motion, or acceleration, of a body. These three laws are the foundation for using kinetics to analyze both linear and angular motion. For more on Newton's laws, turn to Chapter 6.

Linear kinetics

Linear kinetics investigates how forces affect the linear motion, or *translation*, of a body. The characteristics of a force include its size, direction, point of application, and line of action. Each characteristic influences the force's effect on the body, and identifying the characteristics of each force applied to a body is an important step in kinetics. In Chapter 4, I show you how to describe the characteristics of a force and explain what makes gravity pull and friction push.

Angular kinetics

Angular kinetics investigates the causes of angular motion, or *rotation*. The turning effect of a force applied to a body is called *torque*. Torque is produced when a force is applied to a body at some distance from an axis of rotation. I introduce the basic concept of torque in Chapter 8 and explain how the turning effect of a force is affected by manipulating the size of the force or by applying the force farther from the axis.

Putting Biomechanics to Work

When you have the basic tools of kinematics and kinetics, along with a basic understanding of how the neuromusculoskeletal system controls movement, you can use them to analyze movement. In Part V, I show some common applications of using biomechanics to conduct an analysis:

- **Qualitative analysis:** This type of analysis is most frequently done in teaching, coaching, or clinical situations. You can apply the principles of biomechanics to visually evaluate the quality of a performance and provide feedback based on an accurate and specific troubleshooting of the cause of the level of performance.
- **Quantitative analysis:** This type of analysis measures kinematic and kinetic parameters of performance, usually using sophisticated laboratory equipment. It provides a more detailed description of a performance and is most typically used in a research study (or often in a laboratory experience in a biomechanics class).
- **Forensic analysis:** Biomechanics is one of the tools used to resolve criminal and civil legal questions. The principles of biomechanics are combined with evidence gathered by other investigators to answer the question of "whodunit."

Reviewing the Math You Need for Biomechanics

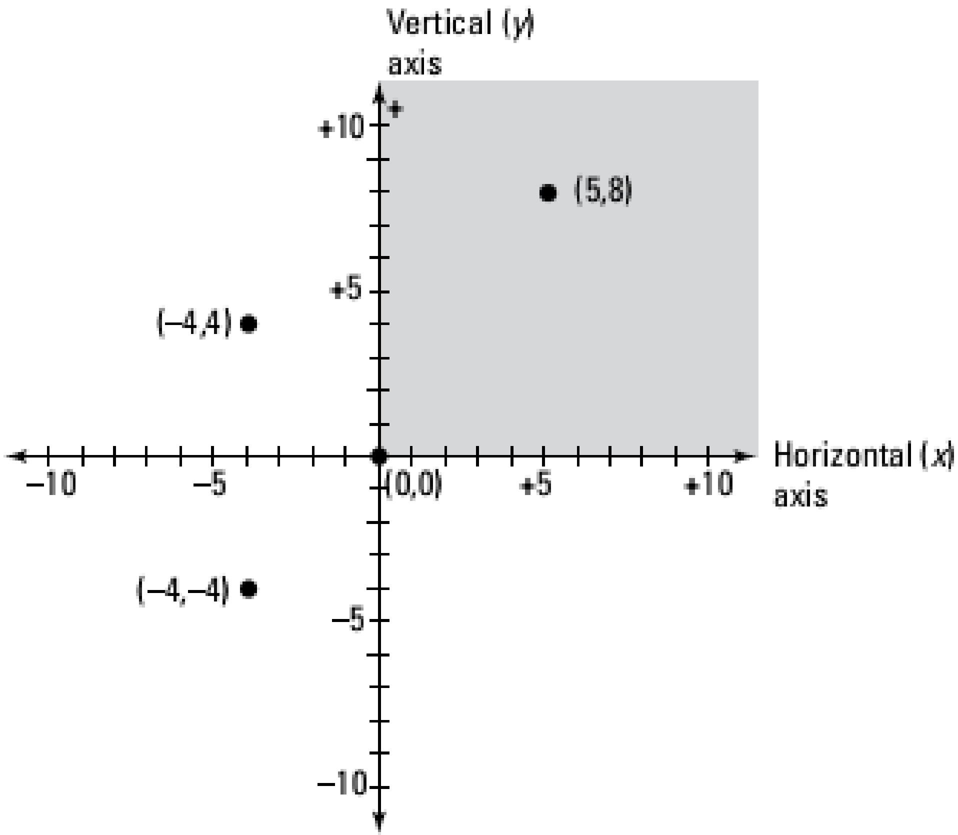


Figure 2-1: A Cartesian coordinate system consists of an *x*-axis and a *y*-axis.

Figure 2-2 shows a right triangle. In a right triangle, one angle is a right angle, measuring 90 degrees. The 90-degree angle is indicated with a small square at the angle.

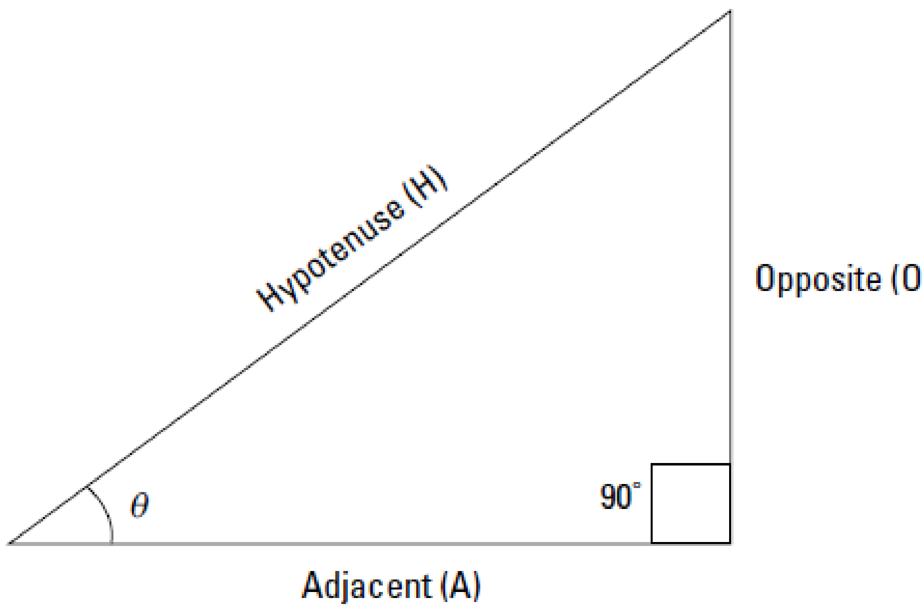


Figure 2-2: A right triangle.

Using the Pythagorean theorem

The Pythagorean theorem relates the length of the three sides of a right triangle. Using the names of the sides of the right triangle in Figure 2-2, the equation for the Pythagorean theorem is written as $\text{Opposite}^2 + \text{Adjacent}^2 = \text{Hypotenuse}^2$ (which can be abbreviated to $O^2 + A^2 = H^2$). The Pythagorean theorem holds true for all right triangles, no matter how long or short the sides are, and no matter the measure of the acute angles.

$O^2 + A^2 = H^2$ is the same Pythagorean theorem as the more familiar $a^2 + b^2 = c^2$.

When the lengths of two sides of a right triangle are known, the Pythagorean theorem is used to calculate the length of the unknown side. For example, if the opposite side is 30 m and the adjacent side is 40 m, you can calculate the length of the hypotenuse.

De-tricking trigonometric functions: SOH CAH TOA

Trigonometry is the field of mathematics describing the relationship between the sides and angles of triangles. Just as the Pythagorean theorem (see the preceding section) allows you to calculate the length of an unknown side of a right triangle when the lengths of two sides are known, the trigonometic functions (or simply trig functions) allow you to calculate the length of the sides of a right triangle if the length of one side and the measure of one acute angle are known. The trig functions expand your toolbox for working with right triangles.

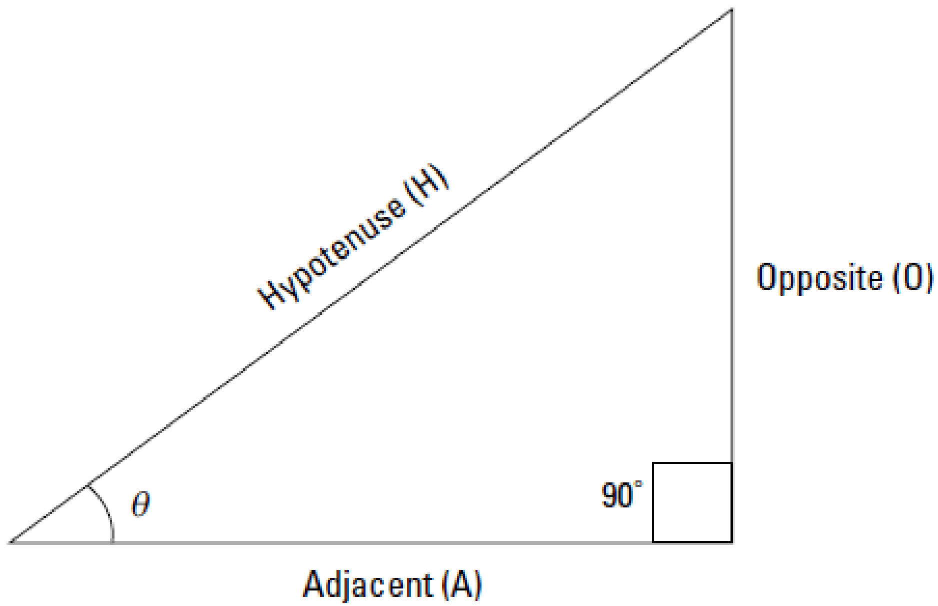
Defining the trig functions

The trig functions specify the ratios between two sides of the right triangle. A *ratio* is the relationship between two measurable quantities, expressed in the format

$$\text{ratio} = \frac{\text{one measurement}}{\text{another measurement}}$$

Or, for a right triangle:

$$\text{trig function} = \frac{\text{length of one side}}{\text{length of another side}}$$



$$\sin\theta = \frac{\text{Opposite}}{\text{Hypotenuse}} = \text{SOH}$$

$$\cos\theta = \frac{\text{Adjacent}}{\text{Hypotenuse}} = \text{CAH}$$

$$\tan\theta = \frac{\text{Opposite}}{\text{Adjacent}} = \text{TOA}$$

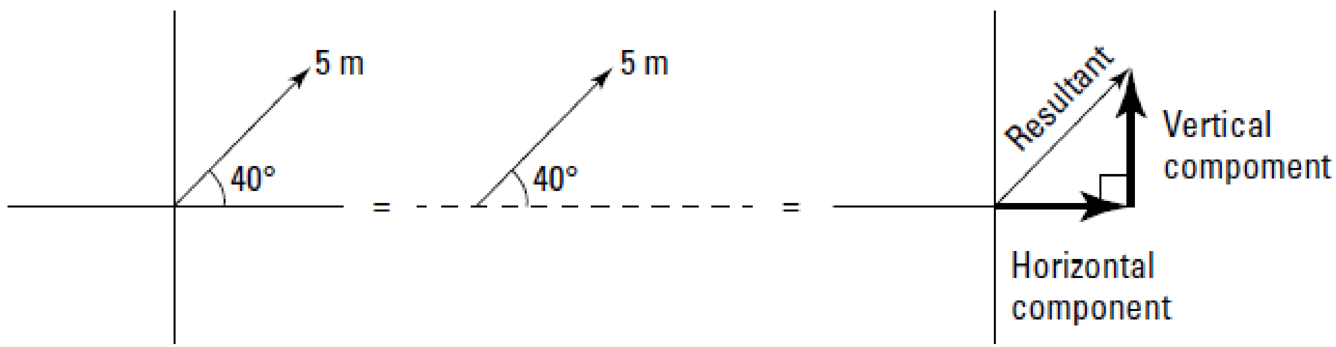
Скаларни и векторни величини

A *quantity* is anything that can be measured. In biomechanics, two types of quantities are important:

- **Scalars:** A *scalar quantity* is any quantity that can be fully described by its magnitude, size, or amount. Scalar quantities include time, mass, distance, and speed. A scalar quantity is fully described by its magnitude, the specific number of units used to measure it — for example, time = 8 seconds (or s), mass = 75 kg, distance = 2 m, or speed = 20 m/s.
- **Vectors:** A *vector quantity* is described not just by its magnitude but also by a direction associated with the quantity. Vector quantities include force, displacement, velocity, and acceleration. Vector quantities are fully described only if *both* magnitude and direction are specified — for example, force = 20 Newtons (or N) to the right, displacement = 5 m at an angle of 40 degrees to the horizontal, velocity = 5 m/s at an angle of 20 degrees to the horizontal, or acceleration = 10 m/s/s downward.

Vectors are drawn on an arbitrary coordinate system of an *x*-axis and a *y*-axis (or *xy*-coordinate system). Figure 2-5 shows the graphic representation of the displacement vector of 5 m at an angle of 40 degrees drawn on an *xy*-coordinate system. The 40-degree angle of its direction is measured from the right horizontal (unless otherwise specified). Sometimes, only part of the coordinate system is drawn, as in the middle part of Figure 2-5. The complete coordinate system is inferred to be present.

Figure 2-5: Vector representation of a displacement of 5 m at an angle of 40 degrees.



Speaking the Language of Biomechanics

Biomechanics involves applying the principles of mechanics to a living body. Sometimes we even use biomechanics to study nonliving things, such as baseball bats, golf balls, and running shoes. But what exactly is mechanics? *Mechanics* is the science studying the effects of forces on a body. *Biomechanics* is a tool for objectively observing, evaluating, and correcting movement to improve performance and reduce the risk of injury.

Measuring Scalars and Vectors

Two important terms in biomechanics are *scalar* and *vector.* These terms refer to the characteristics of something *measured,* or quantified by giving it a numeric value. And a lot of things are measured in biomechanics.

A *scalar quantity* is something described fully by providing a measure of "how much," or the magnitude of the quantity. One very important scalar quantity is *mass,* the measure of how much matter a body contains. In biomechanics, mass is typically measured in kilograms (kg). Other scalar quantities include distance and speed, both measures of the motion of a body.

A *vector quantity* is only fully described if both its magnitude and its direction are reported. One of the most important vector quantities in biomechanics is *force,* a push or a pull that tends to cause a change in the motion of a body. Other vector quantities include displacement, velocity, and acceleration, the basic measures in *kinematics* (the description of the motion of a body).

- ✔ **Vector resolution:** Vectors can be resolved into components, typically a horizontal component and a vertical component (often called the *x* and *y* components) acting at 90 degrees to each other. This process, called *vector resolution,* applies the trigonometric functions of the sine, cosine, and tangent. In Chapter 2, I explain the trigonometric functions and how to use the easy-to-remember anagram SOH CAH TOA when resolving a vector into two components.
- ✔ **Vector composition:** *Vector composition* allows for the combination of two separate vectors into a single resultant vector (resultant because it represents the combined effect of the two vectors). In Chapter 2, I explain this process and show how vector composition uses the Pythagorean theorem and the inverse tangent trigonometric function to compose a resultant from the vectors.

Standardizing a Reference Frame

The whole body and the individual segments of the human body can move in many directions, creating a need to standardize the description of movement. For example, if you're told to raise your arm, you can lift it straight out in front of your body, or lift it out sideways from your body. Both actions raise your arm, but it's confusing if one instruction can cause two different movements of the arm.

Figure 3-1 shows a human body in the *anatomical position,* standing upright, with the arms held out slightly from the sides with the palms of the hands facing forward, and with the feet about shoulder width apart. The anatomical position is the standard reference position for describing the body, although it's not a natural standing position.

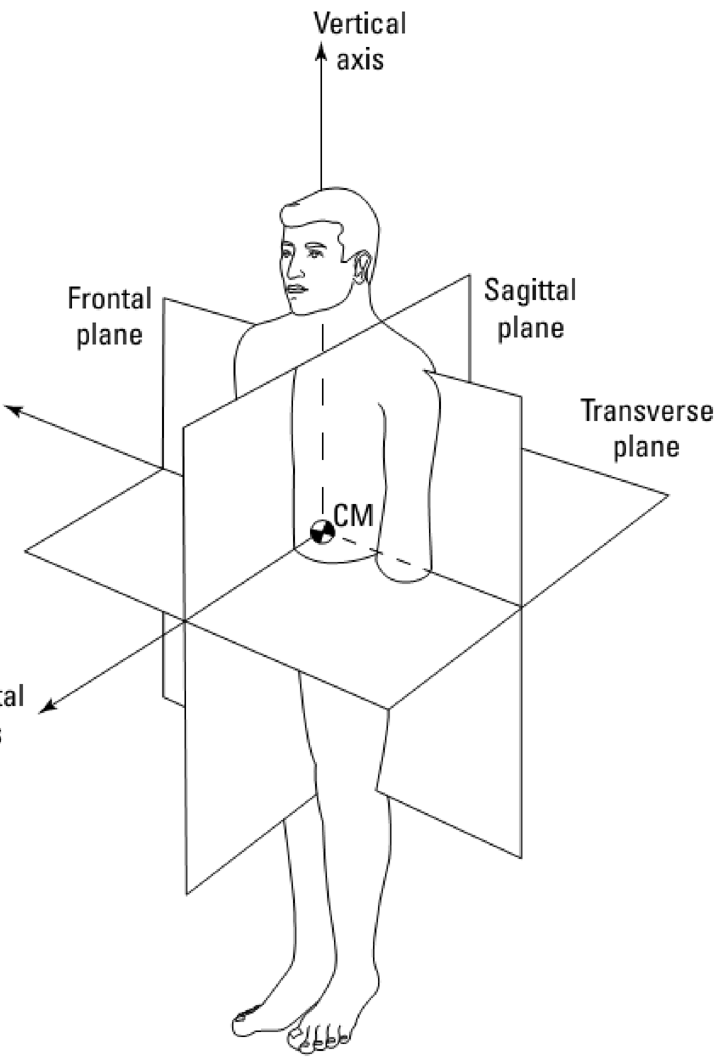


Figure 3-1: The cardinal planes and axes of the human body in the anatomical position.

Describing Movement: Kinematics

Kinematics is the branch of mechanics that describes *motion* (a change in position of a body over a period of time). Kinematics describes the *spatial* (movement through space) and *temporal* (timing) aspects of movement; it isn't concerned with the forces that *cause* the movement. The kinematics of movement are the details of what you see when watching performance.

The basic spatial measures in kinematics include where, how far, how fast, and whether the body is speeding up or slowing down. The timing measures include when, how long, and the sequencing of the component parts of the movement, including the sequential joint actions.

Working with Energy and Power

Another way to look at movement is using the terms *mechanical work*, *mechanical energy*, and *mechanical power* (see Chapter 7).

Mechanical energy

Mechanical energy is defined as the capacity of a body to do work. Any type of energy can be converted from one form to another form, and in the conversion, work is performed. In biomechanics, we're primarily concerned with *mechanical energy,* the energy a body has because it's moving, because of its position, or because it has been deformed.

Kinetic energy (KE) is the energy present in a body when it's moving. The amount of KE is equal to one-half of the product of the mass of the body and its velocity squared, or $KE = \frac{1}{2}mv^2$.

Gravitational potential energy (GPE) is the energy present in a body because of its position above a reference point. The amount of GPE is equal to the product of the mass of the body, the gravitational acceleration (g), and the height it will fall to the reference point (h), or $GPE = mgh$.

Strain energy (SE) is the energy present in a body when it's deformed. The amount of SE in a body is equal to one-half of the body's stiffness (k, a measure of its resistance to deformation) multiplied by the amount of deformation (Δx) squared, or $SE = \frac{1}{2}k\Delta x^2$.

The energy in a body can perform work — that is, the energy can produce a force on a body in the following conditions:

- The KE in a body can perform work on another body that it contacts.
- The GPE in a body can perform work because it will pick up downward velocity as it falls, and the potential energy, because of its position, will convert to KE.
- The SE in a body can perform work on the body as it returns to its original shape.

Turning Force into Torque

The turning effect of a force, its tendency to cause a body to rotate, is called *torque*. Torque is produced when an external force is applied to a body and the line of action of the force doesn't pass through an axis around which the body is able to rotate.

The magnitude of the turning effect depends on the magnitude and direction of the force and the moment arm (MA). As an equation, that's torque = force × moment arm, or $T = F \times MA$. The moment arm measures the perpendicular distance from the line of action of the force to an axis of rotation. A longer MA increases the turning effect of the force. Torque and moment arm are both explained in Chapter 8.

The body's resistance rotation is called the *moment of inertia* (I). The moment of inertia depends not only on the mass of the body, but also on how the mass is distributed around the axis of rotation. In fact, the distribution of the mass has a much greater effect than the size of the mass, as evident in the equation for moment of inertia, $I = mr^2$. In Chapter 10, I explain how a performer can manipulate the moment of inertia of the body to affect its rotation.