# Kinematic Concepts for Analyzing Human Motion

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***After completing this chapter, you will be able to:***

Provide examples of linear, angular, and general forms of motion.

Identify and describe the reference positions, planes, and axes associated with the human body.

Define and appropriately use directional terms and joint movement terminology.

Explain how to plan and conduct an effective qualitative human movement analysis.

Identify and describe the uses of available instrumentation for measuring kinematic quantities.

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Is it best to observe walking gait from a side view, front view, or back view? From what distance can a coach best observe a pitcher's throwing style? What are the advantages and disadvantages of analyzing a movement captured on video? To the untrained observer, there may be no differences in the forms displayed by an elite hurdler and a novice hurdler or in the functioning of a normal knee and an injured, partially rehabilitated knee. What skills are necessary and what procedures are used for effective analysis of human movement kinematics?

One of the most important steps in learning a new subject is mastering the associated terminology. Likewise, learning a general analysis protocol that can be adapted to specific questions or problems within a field of study is invaluable. In this chapter, human movement terminology is introduced, and the problem-solving approach is adapted to provide a template for qualitative solving of human movement analysis problems.

## FORMS OF MOTION

**general motion**
*involving translation and rotation simultaneously*

**linear**
*along a line that may be straight or curved, with all parts of the body moving in the same direction at the same speed*

**angular**
*involving rotation around a central line or point*

**translation**
*linear motion*

Most human movement is general motion, a complex combination of linear and angular motion components. Since linear and angular motion are "pure" forms of motion, it is sometimes useful to break complex movements down into their linear and angular components when performing an analysis.

### Linear Motion

Pure linear motion involves uniform motion of the system of interest, with all system parts moving in the same direction at the same speed. Linear motion is also referred to as translatory motion, or translation. When a body experiences translation, it moves as a unit, and portions of the body do not move relative to each other. For example, a sleeping passenger on a smooth airplane flight is being translated through the air. If the passenger awakens and reaches for a magazine, however, pure translation is no longer occurring because the position of the arm relative to the body has changed.

**rectilinear**
*along a straight line*

**curvilinear**
*along a curved line*

Linear motion may also be thought of as motion along a line. If the line is straight, the motion is rectilinear; if the line is curved, the motion is curvilinear. A motorcyclist maintaining a motionless posture as the bike moves along a straight path is moving rectilinearly. If the motorcyclist jumps the bike and the frame of the bike does not rotate, both rider and bike (with the exception of the spinning wheels) are moving curvilinearly while airborne. Likewise, a Nordic skier coasting in a locked static position down a short hill is in rectilinear motion. If the skier jumps over a gully with all body parts moving in the same direction at the same speed along a curved path, the motion is curvilinear. When a motorcyclist or skier goes over the crest of a hill, the motion is *not* linear, because the top of the body is moving at a greater speed than lower body parts. Figure 2-1 displays a gymnast in rectilinear, curvilinear, and rotational motion.

### Angular Motion

**axis of rotation**
*imaginary line perpendicular to the plane of rotation and passing through the center of rotation*

Angular motion is rotation around a central imaginary line known as the axis of rotation, which is oriented perpendicular to the plane in which the rotation occurs. When a gymnast performs a giant circle on

*Rotation of a body segment at a joint occurs around an imaginary line known as the axis of rotation that passes through the joint center.* Photo © Design Pics/PunchStock.

a bar, the entire body rotates, with the axis of rotation passing through the center of the bar. When a springboard diver executes a somersault in midair, the entire body is again rotating, this time around an imaginary axis of rotation that moves along with the body. Almost all volitional human movement involves rotation of a body segment around an imaginary axis of rotation that passes through the center of the joint to which the segment attaches. When angular motion or rotation occurs, portions of the body in motion are constantly moving relative to other portions of the body.

## General Motion

When translation and rotation are combined, the resulting movement is general motion. A football kicked end over end translates through the air as it simultaneously rotates around a central axis (Figure 2-2). A runner is translated along by angular movements of body segments at the hip, knee, and ankle. Human movement usually consists of general motion rather than pure linear or angular motion.

*•Most human movement activities are categorized as general motion.*

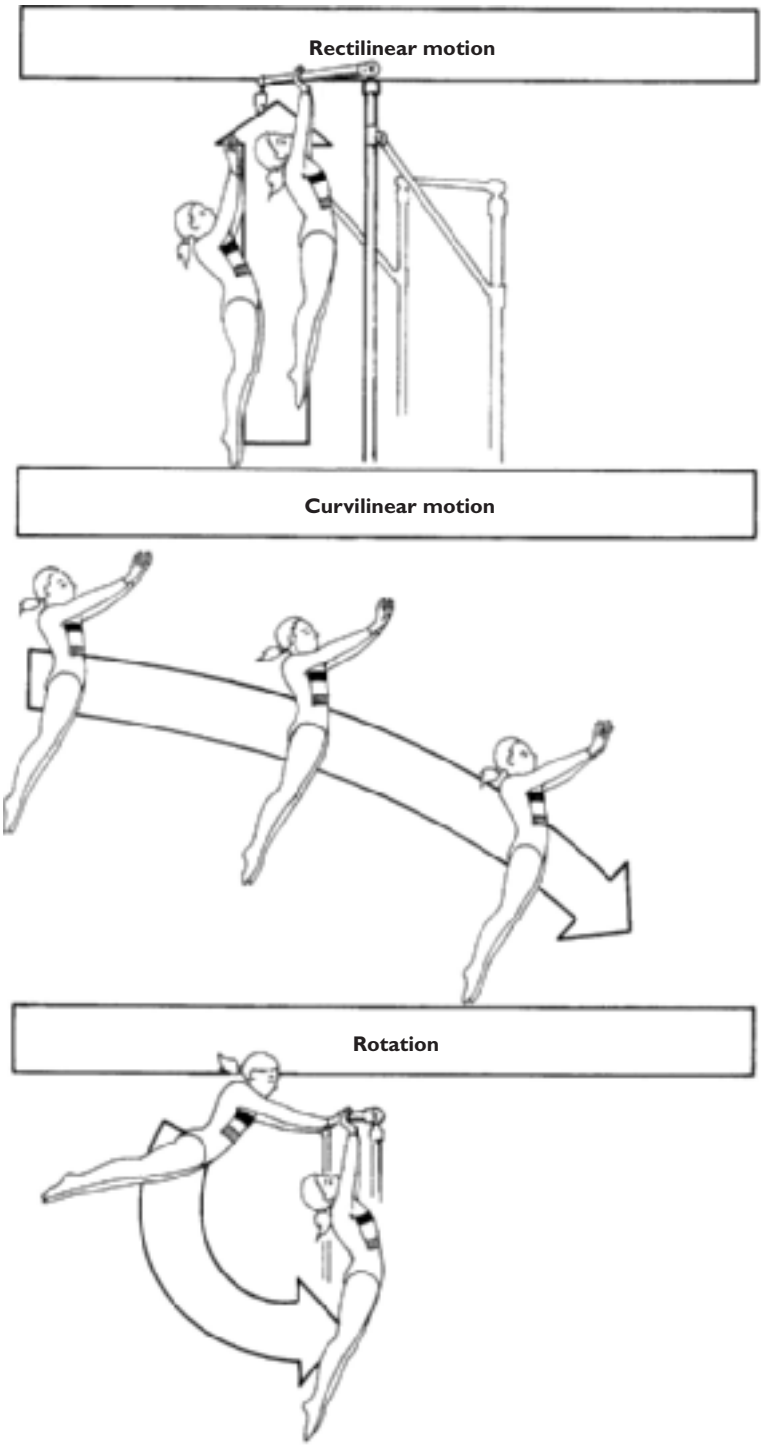
## Mechanical Systems

Before determining the nature of a movement, the mechanical system of interest must be defined. In many circumstances, the entire human body is chosen as the system to be analyzed. In other circumstances, however, the system might be defined as the right arm or perhaps even a ball being projected by the right arm. When an overhand throw is executed, the body as a whole displays general motion, the motion of the throwing arm is primarily angular, and the motion of the released ball is linear. The mechanical system to be analyzed is chosen by the movement analyst according to the focus of interest.

**system**
*object or group of objects chosen by the analyst for study*

**FIGURE 2-1**

Examples of rectilinear, curvilinear, and rotational motion.




## STANDARD REFERENCE TERMINOLOGY

**anatomical reference position**
*erect standing position with all body parts, including the palms of the hands, facing forward; considered the starting position for body segment movements*

Communicating specific information about human movement requires specialized terminology that precisely identifies body positions and directions.

### Anatomical Reference Position

Anatomical reference position is an erect standing position with the feet slightly separated and the arms hanging relaxed at the sides, with the

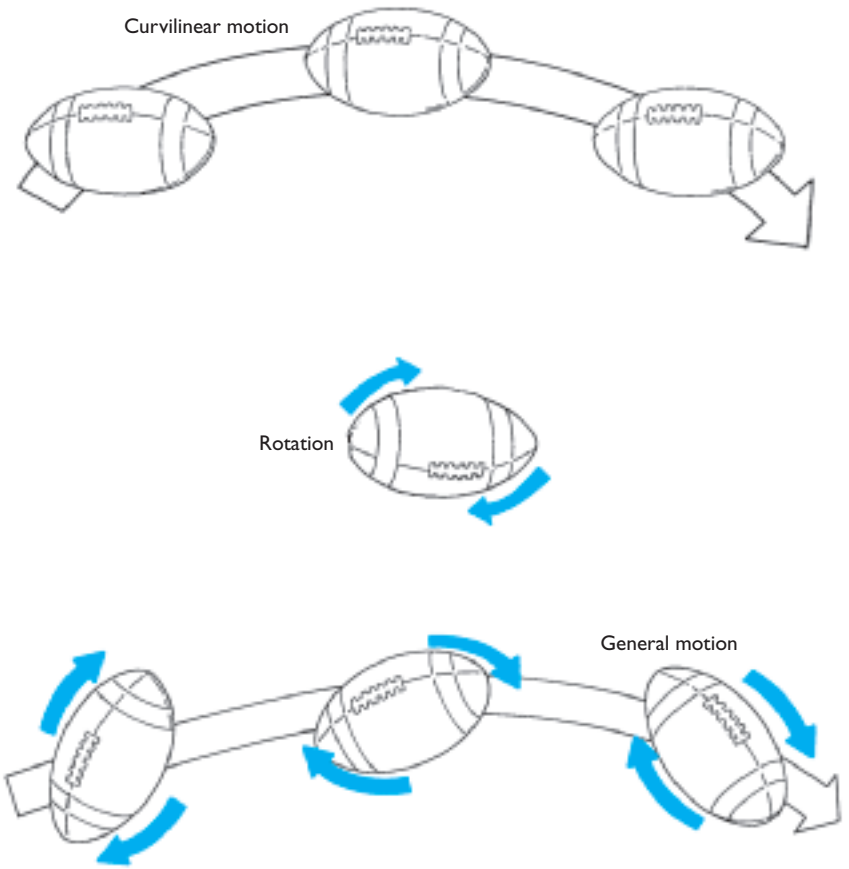



**FIGURE 2-2**

General motion is a combination of linear and angular motion.

palms of the hands facing forward. It is not a natural standing position, but is the body orientation conventionally used as the reference position or starting place when movement terms are defined.

## Directional Terms

In describing the relationship of body parts or the location of an external object with respect to the body, the use of directional terms is necessary. The following are commonly used directional terms:

Superior: closer to the head (In zoology, the synonymous term is *cranial.*)

Inferior: farther away from the head (In zoology, the synonymous term is *caudal.*)

Anterior: toward the front of the body (In zoology, the synonymous term is *ventral.*)

Posterior: toward the back of the body (In zoology, the synonymous term is *dorsal.*)

Medial: toward the midline of the body

Lateral: away from the midline of the body

Proximal: closer in proximity to the trunk (For example, the knee is proximal to the ankle.)

Distal: at a distance from the trunk (For example, the wrist is distal to the elbow.)

Superficial: toward the surface of the body

Deep: inside the body and away from the body surface

*Anatomical reference position.*

*Reference planes and axes are useful in describing gross body movements and in defining more specific movement terminology.*

All of these directional terms can be paired as antonyms—words having opposite meanings. Saying that the elbow is proximal to the wrist is as correct as saying that the wrist is distal to the elbow. Similarly, the nose is superior to the mouth and the mouth is inferior to the nose.

## Anatomical Reference Planes

**cardinal planes**
*three imaginary perpendicular reference planes that divide the body in half by mass*

**sagittal plane**
*plane in which forward and backward movements of the body and body segments occur*

**frontal plane**
*plane in which lateral movements of the body and body segments occur*

**transverse plane**
*plane in which horizontal body and body segment movements occur when the body is in an erect standing position*

*Although most human movements are not strictly planar, the cardinal planes provide a useful way to describe movements that are primarily planar.*

The three imaginary cardinal planes bisect the mass of the body in three dimensions. A *plane* is a two-dimensional surface with an orientation defined by the spatial coordinates of three discrete points not all contained in the same line. It may be thought of as an imaginary flat surface. The sagittal plane, also known as the anteroposterior (AP) plane, divides the body vertically into left and right halves, with each half containing the same mass. The frontal plane, also referred to as the coronal plane, splits the body vertically into front and back halves of equal mass. The horizontal or transverse plane separates the body into top and bottom halves of equal mass. For an individual standing in anatomical reference position, the three cardinal planes all intersect at a single point known as the body's center of mass or center of gravity (Figure 2-3). These imaginary reference planes exist only with respect to the human body. If a person turns at an angle to the right, the reference planes also turn at an angle to the right.

Although the entire body may move along or parallel to a cardinal plane, the movements of individual body segments may also be described as sagittal plane movements, frontal plane movements, and transverse plane movements. When this occurs, the movements being described are usually in a plane that is parallel to one of the cardinal planes. For example, movements that involve forward and backward motion are referred to as sagittal plane movements. When a forward roll is executed, the entire body moves parallel to the sagittal plane. During running in place, the motion of the arms and legs is generally forward and backward, although the planes of motion pass through the shoulder and hip joints rather than the center of the body. Marching, bowling, and cycling are all largely sagittal plane movements (Figure 2-4). Frontal plane movement is lateral (side-to-side) movement; an example of total-body frontal plane movement is the cartwheel. Jumping jacks, side stepping, and side kicks in soccer require frontal plane movement at certain body joints. Examples of total-body transverse plane movement include a twist executed by a diver, trampolinist, or airborne gymnast and a dancer's pirouette.

Although many of the movements conducted by the human body are not oriented sagittally, frontally, or transversely, or are not planar at all, the three major reference planes are still useful. Gross-body movements and specifically named movements that occur at joints are often described as primarily frontal, sagittal, or transverse plane movements.

## Anatomical Reference Axes

**mediolateral axis**
*imaginary line around which sagittal plane rotations occur*

**anteroposterior axis**
*imaginary line around which frontal plane rotations occur*

**longitudinal axis**
*imaginary line around which transverse plane rotations occur*

When a segment of the human body moves, it rotates around an imaginary axis of rotation that passes through a joint to which it is attached. There are three reference axes for describing human motion, and each is oriented perpendicular to one of the three planes of motion. The mediolateral axis, also known as the frontal-horizontal axis, is perpendicular to the sagittal plane. Rotation in the frontal plane occurs around the anteroposterior axis, or sagittal-horizontal axis (Figure 2-5). Transverse plane rotation is around the longitudinal axis, or vertical axis. It is important to recognize that each of these three axes is always associated with the same single plane—the one to which the axis is perpendicular.

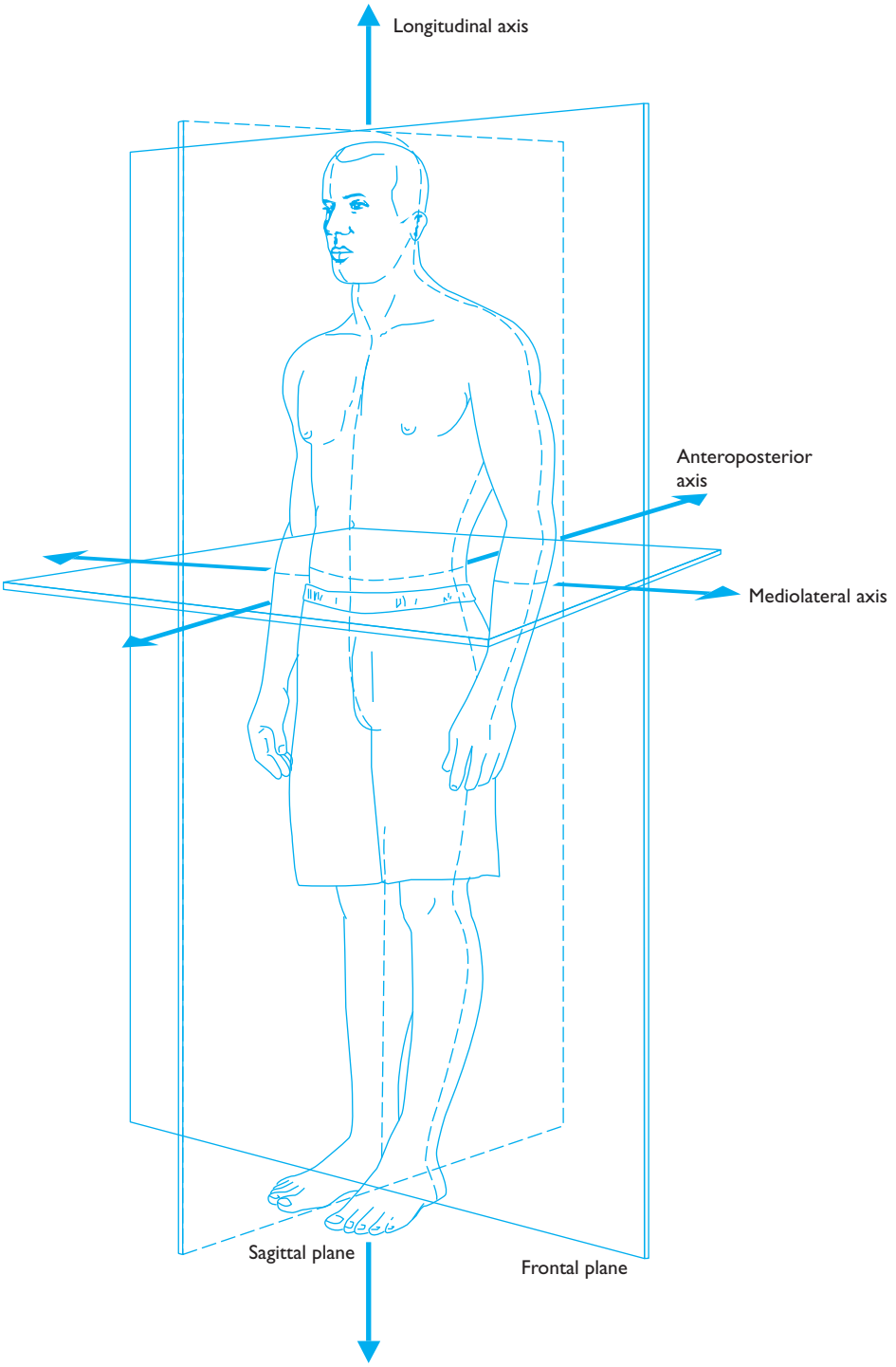



**FIGURE 2-3**

The three cardinal reference planes.

**FIGURE 2-4**

Cycling requires sagittal plane movement of the legs.

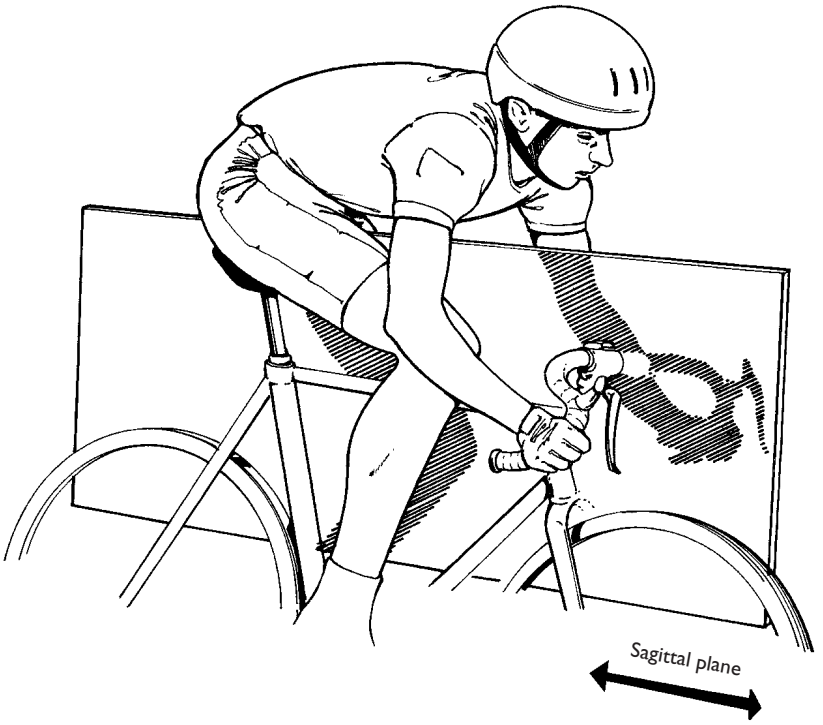
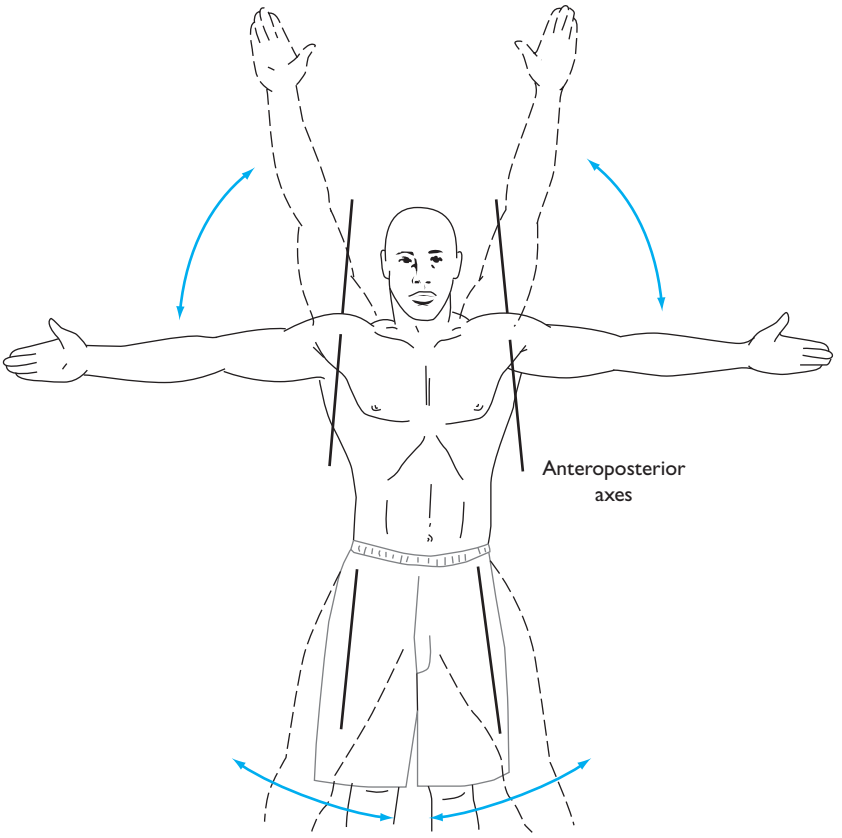



**FIGURE 2-5**

For a jumping jack, the major axes of rotation are anteroposterior axes passing through the shoulders and hips.



## JOINT MOVEMENT TERMINOLOGY

When the human body is in anatomical reference position, all body segments are considered to be positioned at zero degrees. Rotation of a body segment away from anatomical position is named according to the direction of motion and is measured as the angle between the body segment's position and anatomical position.

### Sagittal Plane Movements

From anatomical position, the three primary movements occurring in the sagittal plane are *flexion*, *extension*, and *hyperextension* (Figure 2-6). Flexion includes anteriorly directed sagittal plane rotations of the head, trunk, upper arm, forearm, hand, and hip, and posteriorly directed sagittal plane rotation of the lower leg. Extension is defined as the movement that returns a body segment to anatomical position from a position of flexion, and hyperextension is the rotation beyond anatomical position in the direction opposite the direction of flexion. If the arms or legs are internally or externally rotated from anatomical position, flexion, extension, and hyperextension at the knee and elbow may occur in a plane other than the sagittal.

*•Sagittal plane movements include flexion, extension, and hyperextension, as well as dorsiflexion and plantar flexion.*

Sagittal plane rotation at the ankle occurs both when the foot is moved relative to the lower leg and when the lower leg is moved relative to the foot. Motion bringing the top of the foot toward the lower leg is known as *dorsiflexion*, and the opposite motion, which can be visualized as "planting" the ball of the foot, is termed *plantar flexion* (Figure 2-7).

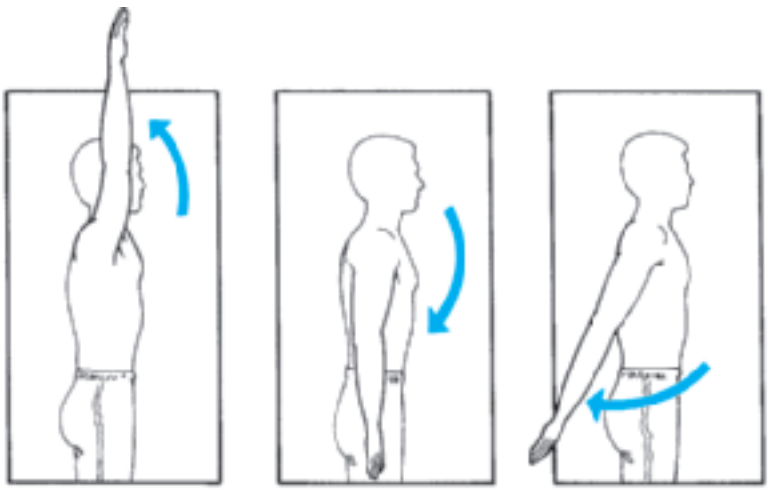



**FIGURE 2-6**

Sagittal plane movements at the shoulder.

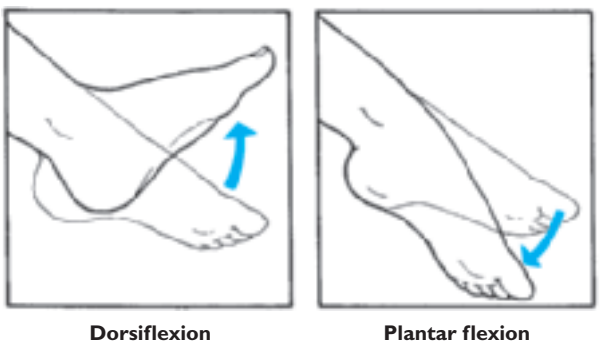



**FIGURE 2-7**

Sagittal plane movements of the foot.

## Frontal Plane Movements

*• Frontal plane movements include abduction and adduction, lateral flexion, elevation and depression, inversion and eversion, and radial and ulnar deviation.*

The major frontal plane rotational movements are *abduction* and *adduction.* Abduction (*abduct* meaning "to take away") moves a body segment away from the midline of the body; adduction (*add* meaning "to bring back") moves a body segment closer to the midline of the body (Figure 2-8).

Other frontal plane movements include sideways rotation of the trunk, which is termed right or left *lateral flexion* (Figure 2-9). *Elevation* and *depression* of the shoulder girdle refer to movement of the shoulder girdle in superior and inferior directions, respectively (Figure 2-10). Rotation of the hand at the wrist in the frontal plane toward the radius (thumb side) is referred to as *radial deviation*, and *ulnar deviation* is hand rotation toward the ulna (little finger side) (Figure 2-11).

Movements of the foot that occur largely in the frontal plane are eversion and inversion. Outward rotation of the sole of the foot is termed *eversion,* and inward rotation of the sole of the foot is called *inversion* (Figure 2-12). Abduction and adduction are also used to describe outward and inward rotation of the entire foot. *Pronation* and *supination* are often used to describe motion occurring at the subtalar joint. Pronation at the subtalar joint consists of a combination of eversion, abduction, and dorsiflexion, and supination involves inversion, adduction, and plantar flexion.

**FIGURE 2-8**

Frontal plane movements at the hip.

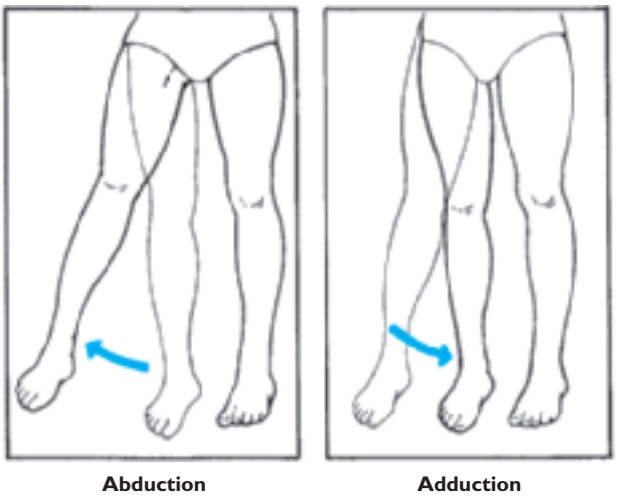
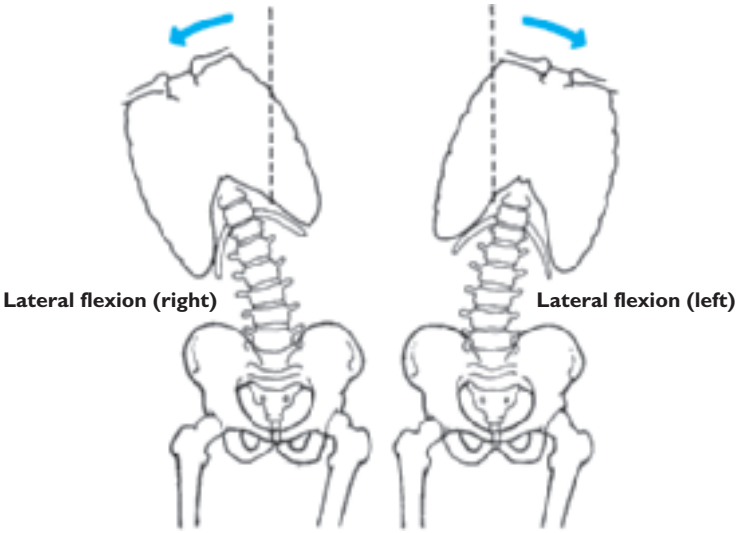



**FIGURE 2-9**

Frontal plane movements of the spinal column.



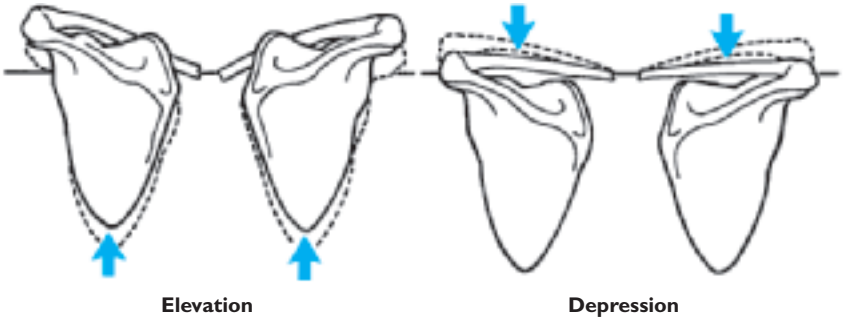



**FIGURE 2-10**

Frontal plane movements of the shoulder girdle.

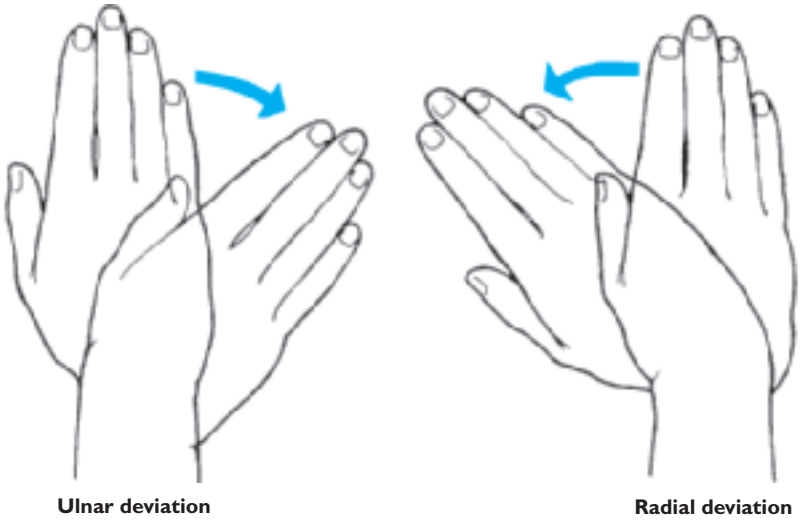



**FIGURE 2-11**

Frontal plane movements of the hand.

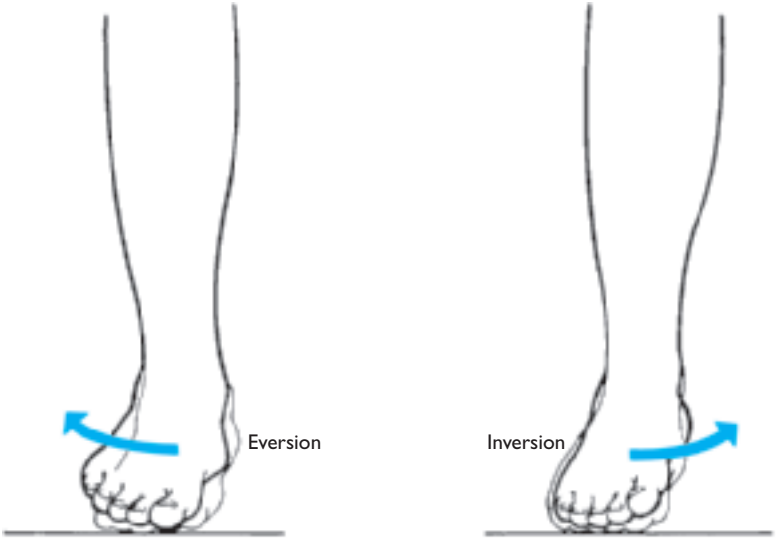
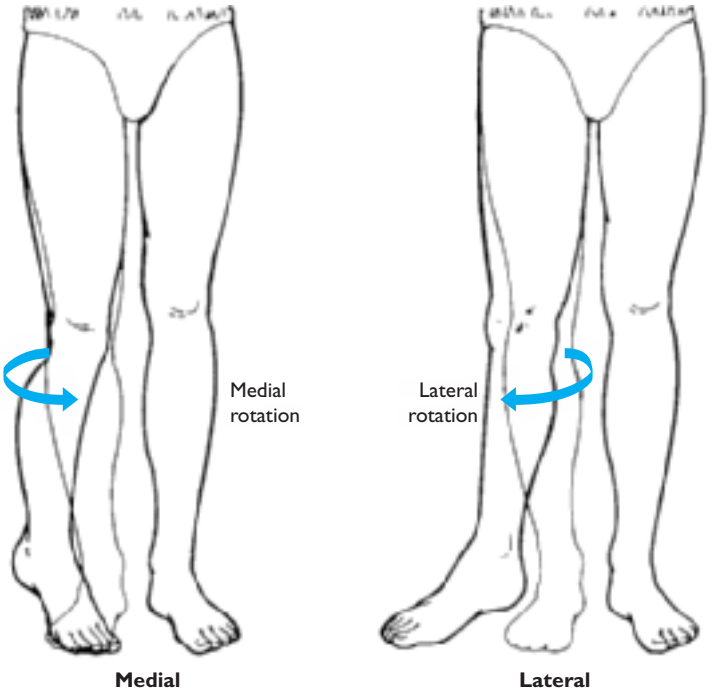



**FIGURE 2-12**

Frontal plane movements of the foot.

**FIGURE 2-13**

Transverse plane movements of the leg.




## Transverse Plane Movements

*• Transverse plane movements include left and right rotation, medial and lateral rotation, supination and pronation, and horizontal abduction and adduction.*

Body movements in the transverse plane are rotational movements about a longitudinal axis. *Left rotation* and *right rotation* are used to describe transverse plane movements of the head, neck, and trunk. Rotation of an arm or leg as a unit in the transverse plane is called *medial rotation,* or internal rotation, when rotation is toward the midline of the body, and *lateral rotation,* or external rotation, when the rotation is away from the midline of the body (Figure 2-13).

Specific terms are used for rotational movements of the forearm. Outward and inward rotations of the forearm are respectively known as *supination* and *pronation* (Figure 2-14). In anatomical position the forearm is in a supinated position.

Although abduction and adduction are frontal plane movements, when the arm or thigh is flexed to a position, movement of these segments in the transverse plane from an anterior position to a lateral position is termed *horizontal abduction*, or horizontal extension (Figure 2-15). Movement in the transverse plane from a lateral to an anterior position is called *horizontal adduction*, or horizontal flexion.

## Other Movements

Many movements of the body limbs take place in planes that are oriented diagonally to the three traditionally recognized cardinal planes. Because human movements are so complex, however, nominal identification of every plane of human movement is impractical.

One special case of general motion involving circular movement of a body segment is designated as *circumduction.* Tracing an imaginary circle in the air with a fingertip while the rest of the hand is stationary requires circumduction at the metacarpophalangeal joint (Figure 2-16). Circumduction combines flexion, extension, abduction, and adduction, resulting in a conical trajectory of the moving body segment.

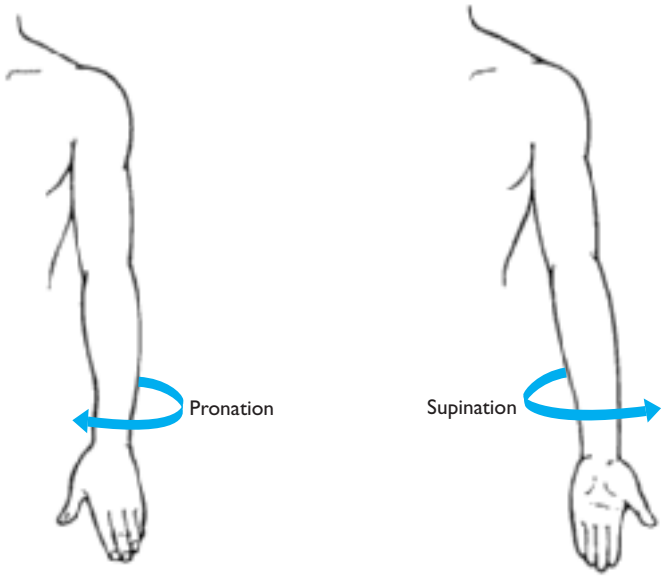



**FIGURE 2-14**

Transverse plane movements of the forearm.

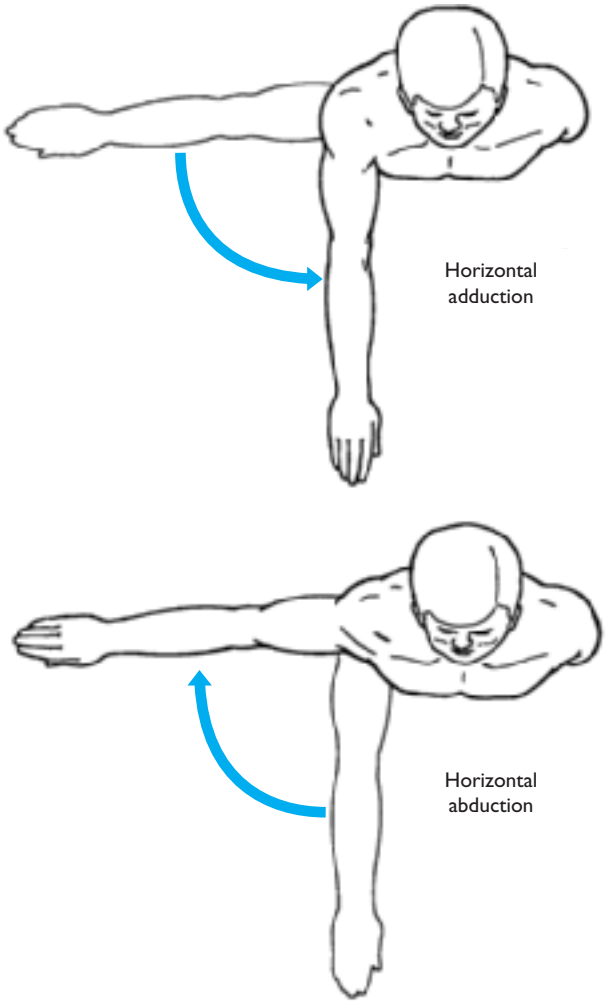
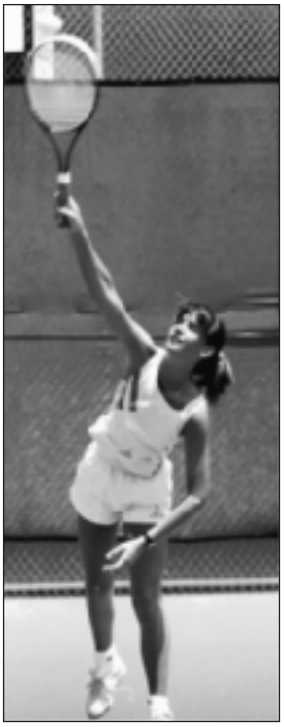



**FIGURE 2-15**

Transverse plane movements at the shoulder.

**FIGURE 2-16**

Circumduction of the index finger at the metacarpophalangeal joint.

*A tennis serve requires arm movement in a diagonal plane.*

## SPATIAL REFERENCE SYSTEMS

Whereas the three cardinal planes and their associated axes of rotation move along with the body, it is also often useful to make use of a fixed system of reference. When biomechanists quantitatively describe the movement of living organisms, they use a spatial reference system to standardize the measurements taken. The system most commonly used is a Cartesian coordinate system, in which units are measured in the directions of either two or three primary axes.

Movements that are primarily in a single direction, or planar, such as running, cycling, or jumping, can be analyzed using a two-dimensional Cartesian coordinate system (Figure 2-17). In two-dimensional Cartesian coordinate systems, points of interest are measured in units in the $x$, or horizontal, direction and in the $y$, or vertical, direction. When a biomechanist is analyzing the motion of the human body, the points of interest are usually the body's joints, which constitute the end points of the body segments. The location of each joint center can be measured with respect to the two axes and described as $(x,y)$, where $x$ is the number of horizontal units away from the $y$-axis and $y$ is the number of vertical units away from the $x$-axis. These units can be measured in both positive and negative directions (Figure 2-18). When a movement of interest is three-dimensional, the analysis can be extended to the third dimension by adding a $z$-axis perpendicular to the $x$- and $y$-axes and measuring units away from the $x,y$ plane in the $z$ direction. With a two-dimensional coordinate system, the $y$-axis is normally vertical, and the $x$-axis horizontal. In the case of a three-dimensional coordinate system, it is usually the $z$-axis that is vertical, with the $x$- and $y$-axes representing the two horizontal directions.

## QUALITATIVE ANALYSIS OF HUMAN MOVEMENT

*• Qualitative analysis requires knowledge of the specific biomechanical purpose of the movement and the ability to detect the causes of errors.*

A good command of the language associated with forms of motion, standard reference terminology, and joint movement terminology is essential for being able to describe a qualitative analysis of human movement. The ability to qualitatively assess human movement also requires both knowl-

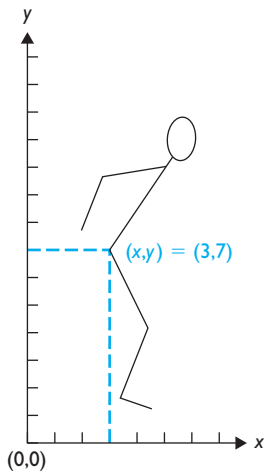



**FIGURE 2-17**

A Cartesian coordinate system showing the $x$ and $y$ coordinates of the hip.

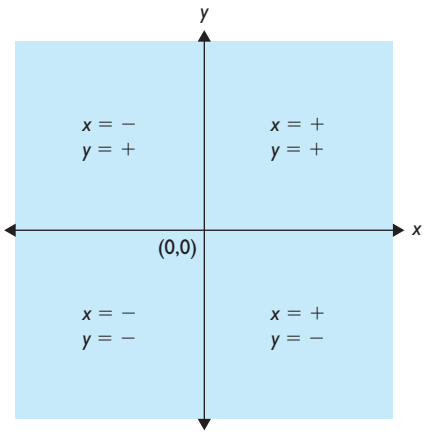



**FIGURE 2-18**

Coordinates can be both positive and negative in a Cartesian coordinate system.

edge of the movement characteristics desired and the ability to observe and analyze whether a given performance incorporates these characteristics. As introduced in Chapter 1, the word *qualitative* refers to a description of quality without the use of numbers. Visual observation is the most commonly used approach for qualitatively analyzing the mechanics of human movement. Based on information gained from watching an athlete perform a skill, a patient walk down a ramp, or a student attempt a novel task, coaches, clinicians, and teachers make judgments and recommendations on a daily basis. To be effective, however, a qualitative analysis cannot be conducted haphazardly, but must be carefully planned and conducted by an analyst with knowledge of the biomechanics of the movement.

## Prerequisite Knowledge for a Qualitative Analysis

There are two main sources of information for the analyst diagnosing a motor skill. The first is the kinematics or technique exhibited by the performer, and the second is the performance outcome. Evaluating performance outcome is of limited value, since the root of optimal performance outcome is appropriate biomechanics.

To effectively analyze a motor skill, it is very helpful for the analyst to understand the specific purpose of the skill from a biomechanical perspective. The general goal of a volleyball player serving a ball is to legally project the ball over the net and into the opposite court. Specifically, this

*Many jobs require conducting qualitative analyses of human movement daily.* Photo courtesy of Digital Vision/Alamy.

requires a coordinated summation of forces produced by trunk rotation, shoulder extension, elbow extension, and forward translation of the total-body center of gravity, as well as contacting the ball at an appropriate height and angle. Whereas the ultimate purpose of a competitive sprint cyclist is to maximize speed while maintaining balance in order to cross the finish line first, biomechanically this requires factors such as maximizing perpendicular force production against the pedals and maintaining a low body profile to minimize air resistance.

Without knowledge of relevant biomechanical principles, analysts may have difficulty in identifying the factors that contribute to (or hinder) performance and may misinterpret the observations they make. More specifically, to effectively analyze a motor skill, the analyst must be able to identify the *cause* of a technique error, as opposed to a symptom of the error, or a performance idiosyncrasy. Inexperienced coaches of tennis or golf may focus on getting the performer to display an appropriate follow-through after hitting the ball. Inadequate follow-through, however, is merely a symptom of the underlying performance error, which may be failure to begin the stroke or swing with sufficient trunk rotation and backswing, or failure to swing the racquet or club with sufficient velocity. The ability to identify the cause of a performance error is dependent on an understanding of the biomechanics of the motor skill.

*•Analysts should be able to distinguish the cause of a problem from symptoms of the problem or an unrelated movement idiosyncrasy.*

One potential source of knowledge about the biomechanics of a motor skill is experience in performing the skill. A person who performs a skill proficiently usually is better equipped to qualitatively analyze that skill than is a person less familiar with the skill. For example, advanced batters demonstrate greater perceptual decision making during a pitch than do intermediate batters, particularly when the pitch is a curve ball (4). In most cases, a high level of familiarity with the skill or movement being performed improves the analyst's ability to focus attention on the critical aspects of the event.

*•Experience in performing a motor skill does not necessarily translate to proficiency in analyzing the skill.*

Direct experience in performing a motor skill, however, is not the only or necessarily the best way to acquire expertise in analyzing the skill. Skilled athletes often achieve success not because of the form or technique they display, but in spite of it! Furthermore, highly accomplished athletes do not always become the best coaches, and highly successful coaches may have had little or no participatory experience in the sports they coach.

The conscientious coach, teacher, or clinician typically uses several avenues to develop a knowledge base from which to evaluate a motor skill. One is to read available materials from textbooks, scientific journals, and lay (coaching) journals, despite the facts that not all movement patterns and skills have been researched and that some biomechanics literature is so esoteric that advanced training in biomechanics is required to understand it. However, when selecting reading material, it is important to distinguish between articles supported by research and those based primarily on opinion, as "commonsense" approaches to skill analyses may be flawed. There are also opportunities to interact directly with individuals who have expert knowledge of particular skills at conferences and workshops.

## Planning a Qualitative Analysis

Even the simplest qualitative analysis may yield inadequate or faulty information if approached haphazardly. As the complexity of the skill and/or the level of desired analytical detail increases, so does the level of required planning.

The first step in any analysis is to identify the major question or questions of interest. Often, these questions have already been formulated by

the analyst, or they serve as the original purpose for the observation. For example, has a post–knee surgery patient's gait returned to normal? Why is a volleyball player having difficulty hitting cross-court? What might be causing a secretary's wrist pain? Or simply, is a given skill being performed as effectively as possible? Having one or more particular questions or problems in mind helps to focus the analysis. Preparing a criteria sheet or a checklist prior to performing an analysis is a useful way to help focus attention on the critical elements of the movement being evaluated. Of course, the ability to identify appropriate analysis questions and formulate a checklist is dependent on the analyst's knowledge of the biomechanics of the movement. When an analyst is observing a skill that is less than familiar, it can be helpful to recall that many motor skills have commonalities. For example, serves in tennis and volleyball and the badminton overhead clear are all very similar to the overarm throw.

*A tennis player's eyes should follow the oncoming ball long enough to enable the player to contact the ball with the racquet.*

The analyst should next determine the optimal perspective(s) from which to view the movement. If the major movements are primarily planar, as with the legs during cycling or the pitching arm during a softball pitch, a single viewing perspective such as a side view or a rear view may be sufficient. If the movement occurs in more than one plane, as with the motions of the arms and legs during the breaststroke or the arm motion during a baseball batter's swing, the observer may need to view the movement from more than one perspective to see all critical aspects of interest. For example, a rear view, a side view, and a top view of a martial artist's kick all yield different information about the movement (Figure 2-19).

The analyst's viewing distance from the performer should also be selected thoughtfully (Figure 2-20). If the analyst wishes to observe subtalar pronation and supination in a patient walking on a treadmill, a close-up rear view of the lower legs and feet is necessary. Analyzing where a particular volleyball player moves on the court during a series of plays under rapidly changing game conditions is best accomplished from a reasonably distant, elevated position.

Another consideration is the number of trials or executions of the movement that should be observed in the course of formulating an analysis. A skilled athlete may display movement kinematics that deviate only slightly across performances, but a child learning to run may take no two steps alike. Basing an analysis on observation of a single performance is usually unwise. The greater the inconsistency in the performer's kinematics, the larger the number of observations that should be made.

- *Repeated observation of a motor skill is useful in helping the analyst to distinguish consistent performance errors from random errors.*
- *Use of a video camera provides both advantages and disadvantages to the movement analyst.*

Other factors that potentially influence the quality of observations of human movement are the performer's attire and the nature of the surrounding environment. When biomechanic researchers study the kinematics of a particular movement, the subjects typically wear minimal attire so that movements of body segments will not be obscured. Although there are many situations, such as instructional classes, competitive events, and team practices, for which this may not be practical, analysts should be aware that loose clothing can obscure subtle motions. Adequate lighting and a nondistracting background of contrasting color also improve the visibility of the observed movement.

A final consideration is whether to rely on visual observation alone or to use a video camera. As the speed of the movement of interest increases, it becomes progressively less practical to rely on visual observation. Consequently, even the most careful observer may miss important aspects of a rapidly executed movement. Video also enables the performer to view the movement, as well as allowing repeated viewing of the movement by analyst and performer, enabling performance feedback that can enhance the learning of a motor skill. Most playback units also enable slow-motion

**FIGURE 2-19**

Whereas skills that are primarily planar may require only one viewing perspective, the movement analyst should view multiplanar skills from more than one direction.

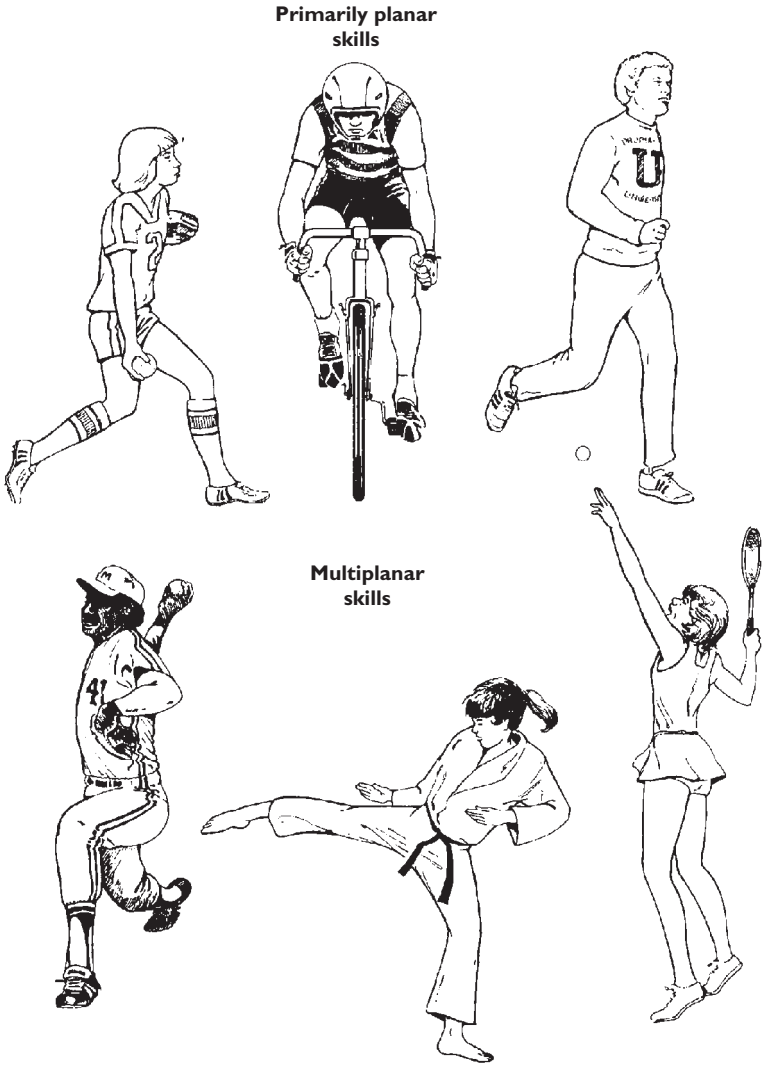
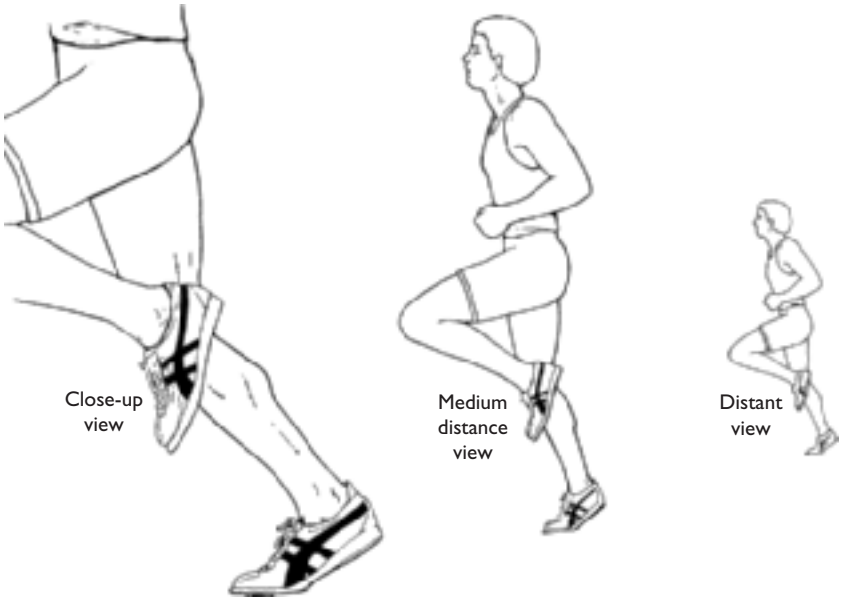



**FIGURE 2-20**

The observation distance between analyst and performer should be selected based on the specific questions of interest.



viewing and single-picture advance that facilitate isolation of the critical aspects of a movement.

The analyst should be aware, however, that there is a potential drawback to the use of video. The subject's awareness of the presence of a camera sometimes results in changes in performance. Movement analysts should be aware that subjects may be distracted or unconsciously modify their techniques when a recording device is used.

## Conducting a Qualitative Analysis

Despite careful planning of a qualitative analysis, new questions occasionally emerge during the course of collecting observations. Movement modifications may be taking place with each performance as learning occurs, especially when the performer is unskilled. Even when this is not the case, the observations made may suggest new questions of interest. For example, what is causing the inconsistencies in a golfer's swing? What technique changes are occurring over the 30–40 m range in a 100 m sprint? A careful analysis is not strictly preprogrammed, but often involves identifying new questions to answer or problems to solve. The teacher, clinician, or coach often is involved in a continuous process of formulating an analysis, collecting additional observations, and formulating an updated analysis (Figure 2-21).

Answering questions that have been identified requires that the analyst be able to focus on the critical aspects of the movement. Once a biomechanical error has been generally identified, it is often useful for the analyst to watch the performer over several trials and to progressively zero in on the specific problem. Evaluating a softball pitcher's technique might begin with observation of insufficient ball speed, progress to an evaluation of upper-extremity kinematics, and end with an identification of insufficient wrist snap at ball release.

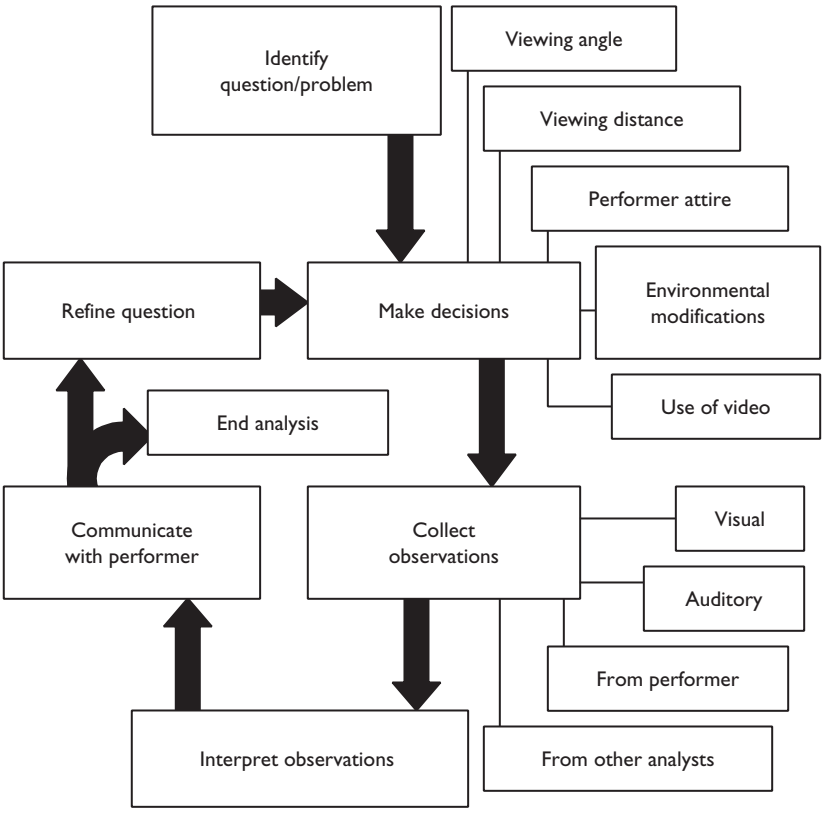



**FIGURE 2-21**

The qualitative analysis process is often cyclical, with observations leading to refinement of the original question.

The analyst should also be aware that every performance of a motor skill is affected by the characteristics of the performer. These include the performer's age, gender, and anthropometry; the developmental and skill levels at which the performer is operating; and any special physical or personality traits that may impact performance. Providing a novice, preschool-aged performer with cues for a skilled, mature performance may be counterproductive, since young children do not have the same motor capabilities as adults. Likewise, although training can ameliorate loss of muscular strength and joint range of motion once thought to be inevitably associated with aging, human movement analysts need increased knowledge of and sensitivity to the special needs of older adults who wish to develop new motor skills. Analysts should also be aware that, although gender has traditionally been regarded as a basis for performance differences, research has shown that before puberty most gender-associated performance differences are probably culturally derived rather than biologically determined (3). Young girls are usually not expected to be as skilled or even as active as young boys. Unfortunately, in many settings, these expectations extend beyond childhood into adolescence and adulthood. The belief that an activity is not gender appropriate has been shown to negatively affect college-aged women's ability to learn a new motor skill (1). Analysts of female performers should not reinforce this cultural misunderstanding by lowering their expectations of girls or women based on gender. Analysts should also be sensitive to other factors that can influence performance. Has the performer experienced a recent emotional upset? Is the sun in his eyes? Is she tired? Being an effective observer requires full awareness of the surrounding environment.

*•Auditory information is often a valuable source in the analysis of human motor skills.*

To supplement visual observation, the analyst should be aware that nonvisual forms of information can also sometimes be useful during a movement analysis. For example, auditory information can provide clues about the way in which a movement was executed. Proper contact of a golf club with a ball sounds distinctly different from when a golfer "tops" the ball. Similarly, the crack of a baseball bat hitting a ball indicates that the contact was direct rather than glancing. The sound of a double contact of a volleyball player's arms with the ball may identify an illegal hit. The sound of a patient's gait usually reveals whether an asymmetry is present.

Another potential source of information is feedback from the performer (Sample Application 2.1). A performer who is experienced enough to recognize the way a particular movement feels as compared to the way a slight modification of the same movement feels is a useful source of information. However, not all performers are sufficiently kinesthetically attuned to provide meaningful subjective feedback of this nature. The performer being analyzed may also assist in other ways. Performance deficiencies may result from errors in technique, perception, or decision making. Identification of perceptual and decision-making errors by the performer often requires more than visual observation of the performance. In these cases, asking meaningful questions of the performer may be useful. However, the analyst should consider subjective input from the performer in conjunction with more objective observations.

Another potential way to enhance the thoroughness of an analysis is to involve more than one analyst. This reduces the likelihood of oversight. Students in the process of learning a new motor skill may also benefit from teaming up to analyze each other's performances under appropriate teacher direction.

*•The ability to effectively analyze human movement improves with practice.*

Finally, analysts must remember that observation skills improve with practice. As analysts gain experience, the analysis process becomes more natural, and the analyses conducted are likely to become more effective

## SAMPLE APPLICATION 2.1

**Problem:** Sally, a powerful outside hitter on a high school volleyball team, has been out for two weeks with mild shoulder bursitis but has recently received her physician's clearance to return to practice. Joan, Sally's coach, notices that Sally's spikes are traveling at a slow speed and are being easily handled by the defensive players.

**Planning the Analysis**

1. What specific problems need to be solved or questions need to be answered regarding the movement? Joan first questions Sally to make sure that the shoulder is not painful. She then reasons that a technique error is present.
2. From what angle(s) and distance(s) can problematic aspects of the movement best be observed? Is more than one view needed? Although a volleyball spike involves transverse plane rotation of the trunk, the arm movement is primarily in the sagittal plane. Joan therefore decides to begin by observing a sagittal view from the side of Sally's hitting arm.
3. How many movement performances should be observed? Since Sally is a skilled player and her spikes are consistently being executed at reduced velocity, Joan reasons that only a few observations may be needed.
4. Is special subject attire, lighting, or background environment needed to facilitate observation? The gym where the team works out is well lit and the players wear sleeveless tops. Therefore, no special accommodations for the analysis seem necessary.
5. Will a video recording of the movement be necessary or useful? A volleyball spike is a relatively fast movement, but there are definite checkpoints that the knowledgeable observer can watch in real time. Is the jump primarily vertical, and is it high enough for the player to contact the ball above the net? Is the hitting arm positioned with the upper arm in maximal horizontal abduction prior to arm swing to allow a full range of arm motion? Is the hitting movement initiated by trunk rotation followed by shoulder flexion, then elbow extension, then snaplike wrist flexion? Is the movement being executed in a coordinated fashion to enable imparting a large force to the ball?

**Conducting the Analysis**

1. Review, and sometimes reformulate, specific questions of focus. After watching Sally execute two spikes, Joan observes that her arm range of motion appears to be relatively small.
2. Repeatedly view movements to gradually zero in on causes of performance errors. After watching Sally spike three more times, Joan suspects that Sally is not positioning her upper arm in maximal horizontal abduction in preparation for the hit.
3. Be aware of the influence of performer characteristics. Joan talks to Sally on the sideline and asks her to put her arm in the preparatory position for a hit. She asks Sally if this position is painful, and Sally responds that it is not.
4. Pay attention to nonvisual cues. (None are apparent in this situation.)
5. When appropriate, ask the performer to self-analyze. Joan tells Sally that she suspects Sally has been protecting the shoulder by not rotating her arm back far enough in preparation for spikes. She can correct the problem. Sally's next few spikes are executed at much faster velocity.
6. Consider involving other analysts to assist. Joan asks her assistant coach to watch Sally for the remainder of practice to determine whether the problem has been corrected.

*Motion analysis software tracks joint markers in three-dimensional space.*

and informative. The expert analyst is typically better able to both identify and diagnose errors than the novice. Novice analysts should take every opportunity to practice movement analysis in carefully planned and structured settings, as such practice has been shown to improve the ability to focus attention on the critical aspects of performance (2).

## TOOLS FOR MEASURING KINEMATIC QUANTITIES

Biomechanics researchers have available a wide array of equipment for studying human movement kinematics. Knowledge gained through the use of this apparatus is often published in professional journals for teachers, clinicians, coaches, and others interested in human movement.

### Video and Film

Photographers began employing cameras in the study of human and animal movement during the late nineteenth century. One famous early photographer was Eadweard Muybridge, a British landscape photographer and a rather colorful character who frequently published essays praising his own work. Muybridge used electronically controlled still cameras aligned in sequence with an electromagnetic tripping device to capture serial shots of trotting and galloping horses, thereby resolving the controversy about whether all four hooves are ever airborne simultaneously (they are). More importantly, however, he amassed three volumes of photographic work on human and animal motions that provided scientific documentation of some of the subtle differences between normal and pathological gait.

Movement analysts today have quite an array of camera types from which to choose. The type of movement and the requirements of the analysis largely determine the camera and analysis system of choice. Standard video provides 30 resolvable pictures per second, which is perfectly adequate for many human movement applications. Scientists and clinicians performing detailed quantitative study of the kinematics of human motion typically require a more sophisticated video camera and playback unit, with higher rates of picture capture. Digital video capture systems designed for human movement analysis are commercially available with frame rates of up to 2000 Hz. For both qualitative and quantitative analysis, however, a consideration often of greater importance than camera speed is the clarity of the captured images. It is the camera's shutter speed that allows user control of the exposure time, or length of time that the shutter is open when each picture in the video record is taken. The faster the movement being analyzed, the shorter the duration of the exposure time required to prevent blurring of the image captured.

Another important consideration when analyzing human movement with video is the number of cameras required to adequately capture the aspects of interest. Because most human movement is not constrained to a single plane, it is typically necessary to use multiple cameras to ensure that all of the movements can be viewed and recorded accurately for a detailed analysis. When practicality dictates that a single camera be used, thoughtful consideration should be given to camera positioning relative to the movement of interest. Only when human motion is occurring perpendicular to the optical axis of a camera are the angles present at joints viewed without distortion.


*Reflective joint markers can be tracked by a camera for automatic digitizing of the movement.*

Biomechanists typically conduct quantitative analyses of human motion by adhering small, reflective markers over the subject's joint centers and other points of interest on the body, with marker locations depending on the purpose of the analysis. High-speed digital video cameras with infrared light rings encircling the lenses then capture high-contrast images of the reflective markers. Since human motion is rarely purely planar, researchers typically position six to eight and sometimes more cameras around the staging area in strategic locations to enable generation of three-dimensional representations of the movements of the markers. Much of today's biomechanical analysis software is capable of providing graphical outputs displaying kinematic and kinetic quantities of interest within minutes after a motion has been digitally captured by the cameras.

*Reflective joint markers can be tracked by a camera for automatic digitizing of the movement.*

*A digital camera with infrared light ring is used for tracking reflective markers on a subject.*

### Other Movement-Monitoring Systems

An *accelerometer* is a transducer used for the direct measurement of acceleration. The accelerometer is attached as rigidly as possible to the body segment or other object of interest, with electrical output channeled to a recording device. Three-dimensional accelerometers that incorporate multiple linear accelerometers are commercially available for monitoring acceleration during nonlinear movements.

## SUMMARY

Movements of the human body are referenced to the sagittal, frontal, and transverse planes, with their respectively associated mediolateral, anteroposterior, and longitudinal axes. Most human motion is general, with both linear and angular components. A set of specialized terminology is used to describe segment motions and joint actions of the human body.

Teachers of physical activities, clinicians, and coaches all routinely perform qualitative analyses to assess, correct, or improve human movements. Both knowledge of the specific biomechanical purpose of the movement and careful preplanning are necessary for an effective qualitative analysis. A number of special tools are available to assist researchers in collecting kinematic observations of human movement.

## INTRODUCTORY PROBLEMS

1. Using appropriate movement terminology, write a qualitative description of the performance of a maximal vertical jump. Your description should be sufficiently detailed that the reader can completely and accurately visualize the movement.
2. Select a movement that occurs primarily in one of the three major reference planes. Qualitatively describe this movement in enough detail that the reader of your description can visualize the movement.
3. List five movements that occur primarily in each of the three cardinal planes. The movements may be either sport skills or activities of daily living.
4. Select a familiar animal. Does the animal move in the same major reference planes in which humans move? What are the major differences

in the movement patterns of this animal and the movement patterns of humans?

5. Select a familiar movement, and list the factors that contribute to skilled versus unskilled performance of that movement.
6. Test your observation skills by carefully observing the two photos shown on the top. List the differences that you are able to identify between these two photos.
7. Choose a familiar movement, and list aspects of that movement that are best observed from close up, from 2 to 3 m away, and from reasonably far away. Write a brief explanation of your choices.
8. Choose a familiar movement, and list aspects of the movement that are best observed from the side view, front view, rear view, and top view. Write a brief explanation of your choices.
9. Choose one of the instrumentation systems described and write a short paragraph explaining the way in which it might be used to study a question related to analysis of a human movement of interest to you.

## ADDITIONAL PROBLEMS

1. Select a familiar movement and identify the ways in which performance of that movement is affected by strength, flexibility, and coordination.
2. List three human movement patterns or skills that are best observed from a side view, from a front or rear view, and from a top view.
3. Select a movement that is nonplanar and write a qualitative description of that movement sufficiently detailed to enable the reader of your description to picture the movement.
4. Select a nonplanar movement of interest and list the protocol you would employ in analyzing that movement.

5. What special expectations, if any, should the analyst have of movement performances if the performer is an older adult? An elementary school–aged girl? A novice? An obese high school–aged boy?
6. What are the advantages and disadvantages of collecting observational data on a sport skill during a competitive event as opposed to a practice session?
7. Select a movement with which you are familiar and list at least five questions that you, as a movement analyst, might ask the performer of the movement to gain additional knowledge about a performance.
8. List the auditory characteristics of five movements and explain in each case how these characteristics provide information about the nature of the movement performance.
9. List the advantages and disadvantages of using a video camera as compared to the human eye for collecting observational data.
10. Locate an article in a professional or research journal that involves kinematic description of a movement of interest to you. What instrumentation was used by the researchers? What viewing distances and perspectives were used? How might the analysis described have been improved?

NAME _____

DATE _____

## LABORATORY EXPERIENCES

1. Observe and analyze a single performer executing two similar but different versions of a particular movement—for example, two pitching styles or two gait styles. Explain what viewing perspectives and distances you selected for collecting observational data on each movement. Write a paragraph comparing the kinematics of the two movements.

Movement selected: _____

Viewing perspectives: _____

Reasons for selection of viewing perspectives: _____

_____

Viewing distances: _____

Reasons for selection of viewing distances: _____

_____

Kinematic comparison: _____

_____

_____

_____

_____

_____

_____

2. Observe a single sport skill as performed by a highly skilled individual, a moderately skilled individual, and an unskilled individual. Qualitatively describe the differences observed.

Sport skill selected: _____

| **Highly Skilled Performer** | **Moderately Skilled Performer** | **Unskilled Performer** |
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3. Select a movement at which you are reasonably skilled. Plan and carry out observations of a less-skilled individual performing the movement, and provide verbal learning cues for that individual, if appropriate. Write a short description of the cues provided, with a rationale for each cue.

Movement selected: _____

| **Cues Provided** | **Rationale** |
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4. Select a partner, and plan and carry out an observational analysis of a movement of interest. Write a composite summary analysis of the movement performance. Write a paragraph identifying in what ways the analysis process was changed by the inclusion of a partner.

Movement selected: _____

**Analysis of Performance**

How the analysis process was different when working with a partner:

5. Plan and carry out a video session of a slow movement of interest as performed by two different subjects. Write a comparative analysis of the subjects' performances.

**Subject 1 Performance**

**Subject 2 Performance**

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2. Jenkins JM, Garn A, and Jenkins P: Preservice teacher observations in peer coaching, *J Teach Phys Educ* 24:2, 2005.
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4. Radlo SJ, Janelle CM, Barba DA, and Frehlich SG: Perceptial decision making for baseball pitch recognition: using P300 latency and amplitude to index attentional processing, *Res Q Exerc Sport* 72:22, 2001.


## ANNOTATED READINGS


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*Provides an introductory look at the mechanics of sport to help readers understand and incorporate technology to enhance training, identify errors in technique, and improve performance.*

Hudson JL: Applied biomechanics in an instructional setting, *JOPERD* 77:25, 2006.

*Describes application of biomechanics in analyzing sport skills in a practical context.*

Payton C and Bartlett R (eds.): *Biomechanical evaluation of movement in sport and exercise,* New York, 2008, Routledge.

*Practical guide to using the range of biomechanics movement analysis equipment and software available today, including detailed explanations of the theory underlying biomechanics testing along with advice concerning choice of equipment and how to use laboratory equipment most effectively.*

Reiman M and Manske R: *Functional testing in human performance,* Champaign, IL, 2009, Human Kinetics.

*Serves as a comprehensive reference on functional testing for assessment of physical activities in sport, recreation, work, and daily living.*


## RELATED WEBSITES

Mikromak
http://www.mikromak.com

*Advertises video hardware and software for sports, medicine, and product research.*

Motion Analysis Corporation
http://www.motionanalysis.com

*Offers an optical motion capture system utilizing reflective markers for entertainment, biomechanics, character animation, and motion analysis.*

Northern Digital, Inc.
http://www.ndigital.com

*Presents optoelectronic 3-D motion measurement systems that track light-emitting diodes for real-time analysis.*

Qualisys, Inc.
http://www.qualisys.com

*Presents a system in which cameras track reflective markers, enabling real-time calculations; applications described for research, clinical, industry, and animation.*

Redlake Imaging
http://www.redlake.com/imaging

*Advertises high-speed video products for scientific and clinical applications.*

SIMI Reality Motion Systems
http://www.simi.com

*Describes computer-based video analysis for the human body and cellular applications; includes demo of gait analysis, among others.*

## KEY TERMS

| | |
|---|---|
| **anatomical reference position** | erect standing position with all body parts, including the palms of the hands, facing forward; considered the starting position for body segment movements |
| **angular** | involving rotation around a central line or point |
| **anteroposterior axis** | imaginary line around which frontal plane rotations occur |
| **axis of rotation** | imaginary line perpendicular to the plane of rotation and passing through the center of rotation |
| **cardinal planes** | three imaginary perpendicular reference planes that divide the body in half by mass |
| **curvilinear** | along a curved line |
| **frontal plane** | plane in which lateral movements of the body and body segments occur |
| **general motion** | motion involving translation and rotation simultaneously |
| **linear** | along a line that may be straight or curved, with all parts of the body moving in the same direction at the same speed |
| **longitudinal axis** | imaginary line around which transverse plane rotations occur |
| **mediolateral axis** | imaginary line around which sagittal plane rotations occur |
| **rectilinear** | along a straight line |
| **sagittal plane** | plane in which forward and backward movements of the body and body segments occur |
| **system** | mechanical system chosen by the analyst for study |
| **translation** | linear motion |
| **transverse plane** | plane in which horizontal body and body segment movements occur when the body is in an erect standing position |