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Chapter 9: Biomechanics

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Definitions in Biomechanics

Biomechanics is a discipline. A discipline deals with understanding, predicting, and explaining phenomena within a content domain, and biomechanics is the study of the human body in motion. By applying principles from mechanics and engineering, biomechanists are able to study the forces that act on the body and the effects they produce (Bates, 1991). Hay (1973) describes biomechanics as the science that examines forces acting on and within a biological structure and the effects produced by such forces, whereas Alt (1967) describes biomechanics as the science that investigates the effect of internal and external forces on human and animal bodies in movement and at rest. Each of these definitions describes the essential relationship between humans and mechanics found in biomechanics.

Kinesiology, the parent discipline of biomechanics, is a science that investigates movement. It can be divided into the mechanical and anatomical aspects of human movement. The mechanical aspects can be further subdivided into statics and dynamics. **Statics** is a branch of mechanics that investigates bodies, masses, and forces at rest or in equilibrium. **Dynamics** investigates bodies, masses, and forces in motion. Dynamics consists of temporal analysis, kinematics, and kinetics. **Temporal analysis** uses time as the sole basis for analysis. **Kinematics** investigates motion without reference to masses or forces. **Kinetics** investigates the actions of forces in producing or changing the motion of masses.

In the United States, the use of mathematical and mechanical principles to study human movement was initially called kinesiology; in Europe, it was called biomechanics (Nelson, 1980). Although there has been considerable controversy over the years as to the correct name for this area of study, it seems to have been settled with biomechanics as the most accepted term worldwide.

In biomechanics, movement is studied in order to understand the underlying mechanisms involved in the movement or in the acquisition and regulation of skill. The uniqueness of biomechanics as an area of study evolves not from the unique body of knowledge but from the questions that are asked relative to understanding human movement (Bates, 1991). Techniques and methods from other scientific disciplines, such as physics and engineering, are used to examine human movement. In this way, biomechanics involves mechanical measurements used in conjunction with biological interpretations (Higgins, 1985). Thus, biomechanics is a key area of study within the realm of exercise science.

The study of movement involves explaining and understanding the structural and functional mechanisms underlying human performance, in all its presentations, from fundamental motor skills to demanding exercise. Higgins (1977) proposed that skill is a movement that allows the organism to respond or act effectively within the environment and to integrate past and present. To become skillful requires mastery of the redundant degrees of freedom (Bernstein, 1967). These degrees of freedom or constraints are morphological (having to do with the body's structure), biomechanical, environmental, and task specific (Higgins, 1977). The study of these constraints is required in order to explain and understand the underlying mechanisms of movement. Thus, movement must be approached from an interdisciplinary perspective. Movement, as a very broad phenomenon, appears in many different forms: play, dance, sport, work, and daily living activities. This is why a biomechanist cannot study meaningful questions without adequate preparation in such areas as anatomy, motor control, physics, exercise physiology, and engineering.

History of Biomechanics

The history of biomechanics can be traced back to the ancient Greeks. According to Nigg and Herzog (1994), the contribution to biomechanics during the period 700 BCE to 200 CE included the distinction between facts and fiction in the discipline, development of mechanical and mathematical models, development of anatomical models, and the first attempt to examine the human body biomechanically.

Aristotle (384–322 BCE) was the first to examine and write about complex movements such as running and walking. He said, "The animal that moves makes its change of position by pressing against that which is beneath it. Hence, athletes jump farther if they have the weights in their hands than if they have not, and runners run faster if they swing their arms, for in extension of the arms there is a kind of leaning upon the hands and wrists" (Nigg & Herzog, 1994). Archimedes (287–212 bce) was the first to examine floating bodies and their movements in the water.

Hippocrates (460–377 BCE), the Father of Western Medicine, advocated that humans should base observations on and draw conclusions from only what was perceived through the senses. Galen (131–201) was the physician of the gladiators. He developed anatomical descriptions and the present-day terminology in use in certain biological fields. During the Renaissance, Leonardo da Vinci (1452–1519) examined the structure and function of the human body in a variety of movements. The contribution of the Renaissance period of 1450 to 1527 to biomechanics included the awakening of science, the foundation of modern anatomy and physiology, and an early examination of movement and muscle action (Nigg & Herzog, 1994). In the modern era, another group of scientists contributed to the growth of biomechanics. Galileo Galilei (1564–1642) studied the action of falling bodies and laid the basis for the mechanical analysis of movement.

> *Focus Point: The famous story in which Galileo is said to have dropped a weight form the Leaning Tower of Pisa is false. The actual experiment was done by Simon Stevin several years before Galileo's work.*

Alfonso Borelli (1608–1679), a student of Galileo, examined muscular movement and mechanical principles. His work *De Motu Animalium* is the first biomechanical "textbook," in which he combined the sciences of mathematics, physics, and anatomy. Isaac Newton (1642–1727) developed his famous mechanical laws and was the founder of calculus, statics, and dynamics. Contributions to biomechanics during this time period included Newtonian mechanics, which provided a theory for mechanical analysis, as well as an improvement in science through development of the process of theory and experimentation (Nigg & Herzog, 1994).

During the 19th century, contributions to biomechanics included the foundation of electromyography, the development of measuring techniques to examine the kinematics and kinetics of movement, and the beginning of the use of engineering principles in biomechanical analysis (Nigg & Herzog, 1994). The Weber brothers (around 1836) investigated the influence of gravity on limb movements in walking and running and were the first to study the path of the center of gravity during movement. Eadweard Muybridge (1830–1894) was the first to develop cinematographical serial pictures to study animals (horses) and humans. Étienne Jules Marey (1830–1904) used various photographic methods to examine movement.

During the 20th century, biomechanics became an academic discipline with graduate programs and faculty positions; biomechanical research influenced applications in industrial, medical, and other practical areas; and biomechanics evolved as a necessary discipline-based method in the study of human and animal movement (Nigg & Herzog, 1994). During this time period, Jules Amar (1879–1935) summarized the physical and physiological aspects related to industrial work. His book, *The Human Motor*, was translated into English in 1920 and set the standards for human engineering in the United States and Europe. Nicholas Bernstein (1896–1966) examined walking, running, and jumping. He laid the foundation for the study of motor control and coordination. A. V. Hill (1886–1977) investigated efficiency and energy cost in human movement, and in 1931, W. O. Fenn published the first biomechanical works in the exercise and sport science literature, a cinematographical analysis of sprint running (Fenn, 1929, 1931).

> *Focus Point: Christian Wilhelm Braune (1831–1892) and Otto Fischer (1861–1917) were the founders of the scientific method of studying human movement, which resulted in the development of the prosthesis.*

In the 1960s, the term *biomechanics* began appearing with more frequency in the literature, and biomechanics finally became a graduate specialization, first at Pennsylvania State University and then at the University of Indiana. Richard Nelson developed a laboratory for biomechanical research at Penn State in 1966, and it was the first that was identified with the term *biomechanics* (Atwater, 1980). His initial graduates were Doris Miller and Charles Dillman. Following his graduation, Charles Dillman went to the University of Illinois to establish a biomechanics program. John Cooper developed a similar laboratory at the University of Indiana in 1967. The first graduate of this program was Barry Bates, who later developed the biomechanics program at the University of Oregon. From these pioneer programs and their graduates, many programs around the country were developed. Others who made tremendous contributions to the development of biomechanics programs around the nation were James Hay (University of Iowa), Stanley Plagenhoef (University of Massachusetts), and Carol Widule (Purdue University).

> *Focus Point: In the United States, the first North American meeting in biomechanics was organized by John Cooper at Indiana University in 1970 (Cooper, 1971).*

The period from 1966 to the present has been an era of great growth in biomechanics. It includes the development of a number of new societies, journals, and professional meetings, such as the First International Seminar on Biomechanics, which was held in Zurich, Switzerland, in 1967 (Wilkerson, 1997), and the origination of the *Journal of Biomechanics* in 1968.

In 1973, the Fourth International Seminar on Biomechanics was held at Penn State University (Bates, 1974). This marked the foundation of the International Society of Biomechanics (ISB). In 1975, the Fifth International Seminar on Bio-mechanics in Jyvaskyla, Finland, marked the conceptualization of the American Society of Biomechanics (ASB), which was founded the following year in Chicago, Illinois. This society includes members from physical education, medicine, ergonomics, biology, and engineering (Wilkerson, 1997).

Another important meeting was held in 1977 at the University of Illinois: the first national conference on teaching kinesiology. At this conference, the differences between the terms *biomechanics* and *kinesiology* were discussed at length. Kinesiology was found to vary from a name of a course to a title of a college department (Dillman &

Sears, 1978). It was also found that in the United States, the use of mathematical and mechanical principles to study human movement was initially called kinesiology, whereas in Europe it was called biomechanics (Nelson, 1980). *Kinesiology* was defined as the parent discipline of biomechanics and generally of the science that investigates movement. *Biomechanics* was defined as a discipline for the study of forces that act on the body and the effects they produce.

In 1982, the International Society of Biomechanics in Sport (ISBS) was founded in San Diego, California (Terauds, 1982). More recently, an international electronic mail communication list with the name biomch-L (Biomechanics-List) was established at the University of Calgary, Canada, to help biomechanists from all over the world exchange ideas, problems, information, and the like (Bogert & Gielo-Perczak, 1992). Finally, in 1989, the Academy of Physical Education was renamed the Academy of Kinesiology and Physical Education, because kinesiology was defined as the overall science of human movement (Charles, 1994). As a result, in 1993, the Kinesiology Academy of the American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD), which was representing the biomechanics section, was renamed the Biomechanics Academy to more clearly identify its role (Wilkerson, 1997).

Exhibit 9.1 summarizes important events in the history of biomechanics.

Important dates in biomechanics.	
Date	Event
384-322 BCE	Aristotle examined and wrote about complex movements such as running and walking.
1452-1519	Leonardo da Vinci examined the function of the human body.
1608-1679	Alfonso Borelli wrote the first biomechanical text, De Motu Animalium.
1642-1727	Sir Isaac Newton developed calculus and his mechanical laws
1830-1894	Eadweard Muybridge developed cinematographical serial pictures to study animals and humans.
1920	Jules Amar's book, The Human Motor, was translated into English.
1931	W. O. Fenn published about the cinematographical analysis of sprint running.
1966	Richard Nelson developed the first laboratory for biomechanical research at Penn State
1967	First International Seminar on Biomechanics, Zurich, Switzerland
1968	Origination of the Journal of Biomechanics.
1973	Founding of the International Society of Biomechanics.
1976	Founding of the American Society of Biomechanics.

1982	Founding of the International Society of Biomechanics in Sports
1993	The Kinesiology Academy of AAHPERD was renamed the Biomechanics Academy of AAHPERD

Areas of Study in Biomechanics

Using similar techniques and instruments, biomechanists work in a variety of areas. Each of these areas can be identified and the type of research described. The five areas discussed here are developmental biomechanics, biomechanics of exercise and sports, rehabilitative biomechanics, occupational biomechanics, and forensic biomechanics.

Developmental Biomechanics

Biomechanical research in human development focuses on evaluating essential movement patterns across the life span. Individuals of different ages are examined while performing a variety of daily-living motor skills. The activities can then be quantified, described, and analyzed. Biomechanical analysis is specifically important in quantifying the developmental motor skills and movement patterns such as walking, kicking, jumping, throwing, and catching. This research resulted in the description of a typical activity pattern for each age group. This pattern can then be compared to an individual's performance to determine his or her level of ability at any age. This type of analysis has also been performed for a variety of other activities of daily living across the life span, including ascending and descending stairs, raising from and lowering to a different level (such as a chair or bed), lifting and carrying objects, pushing and pulling objects, and working with short- and long-handled implements. Again, evaluations and quantification of each type of activity at a variety of age levels allowed comparisons to be made between age levels and made it possible to evaluate an individual's skill or ability in a specific activity at a particular age.

For example, biomechanics experts have used high-speed camera systems and force platforms to capture and analyze slight movement changes in young children. Based on this information, biomechanists objectively examine movements such as body sway during sitting and standing, and/or the range of motion at the joints during walking. These results are then shared with pediatricians and pediatric physical therapists to accurately evaluate developmental motor milestones during infancy and childhood. In particular, such objective biomechanical measurements are used to evaluate therapies for children with developmental movement disorders (e.g., global developmental delay, cerebral palsy, Down syndrome).

Another example is biomechanical research focused on the aging process. Through the developmental process, aging is the ultimate and inevitable stage. Activity levels and working capacity are diminished in older adults. Physiological and motor performance, such as reaction time, movement time, muscle strength, and flexibility, are also reduced with age. Biomechanical analysis is commonly used to assess movement changes in older adults in order to identify the causes of slips, trips, and falls that the elderly population experiences. In addition, biomechanists strive to develop biotechnology that can improve the quality of life for the elderly, prevent injury, and quantify the best treatment approaches for restoring diminished balance and other motor abilities.

Biomechanics of Exercise and Sport

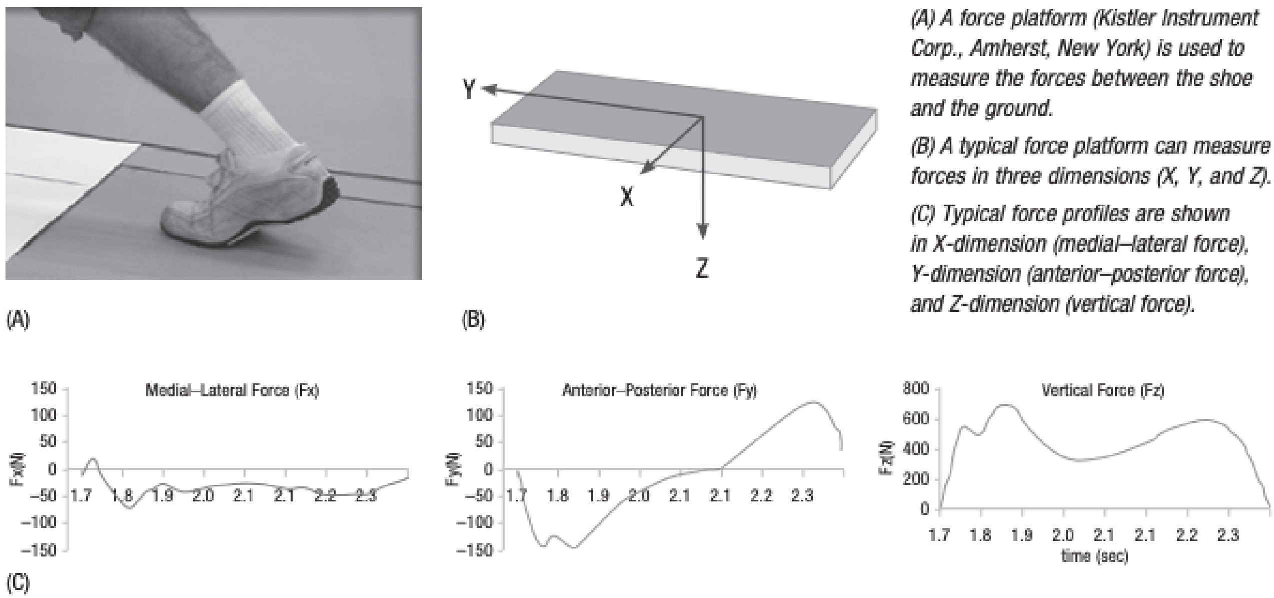
Biomechanical research in the area of exercise and sport has focused on postures and movement patterns that minimize the risk of injury during physical activity and improve performance. Among the contributions of biomechanics are the development of exercise machines for improving strength, endurance, flexibility, and speed; the development of new exercise modes, such as plyometrics and isokinetics, to improve performance; the design of exercise and sports equipment to minimize injuries; and the development of exercise and sport techniques to optimize performance.

The design of sport footwear is an example of the use of biomechanics to improve performance and reduce injury. Until the beginning of the 1970s, changes in the design of sport shoes were based on the subjective observations of athletes and coaches. Because the movements of the lower extremities were too fast to be evaluated with the naked eye or even standard film cameras, a new technology needed to be developed. A welcome invention was high-speed cinematography. Sixteen-millimeter film taken at high speed could be displayed at normal speed or evaluated frame by frame for a detailed examination of the movement of the foot and leg during contact with the ground while walking or running. Today, advanced digital video camera systems are used to capture movements in sports that are extremely fast, such as the golf swing and the baseball pitch.

> *Focus Point: Among the contributions of biomechanics are the development of exercise machines for improving strength, endurance, flexibility, and speed; the development of new exercise modes, such as plyometrics and isokinetics, to improve performance; the design of exercise and sports equipment to minimize injuries; and the development of exercise and sports techniques to optimize performance.*

The amount of force that is applied to a surface or an individual during a sport activity is also important to the biomechanist. To determine this force, biomechanists developed special scales, known as **force platforms** (Exhibit 9.2), that can measure the impact forces between the shoe and the ground. By measuring these forces, we know today that the foot and the shoe must absorb two to three times the body’s weight with each running step.

Exhibit 9.2: Force platforms.



(A) A force platform (Kistler Instrument Corp., Amherst, New York) is used to measure the forces between the shoe and the ground.

(B) A typical force platform can measure forces in three dimensions (X, Y, and Z).

(C) Typical force profiles are shown in X-dimension (medial–lateral force), Y-dimension (anterior–posterior force), and Z-dimension (vertical force).

Another recently developed device is an insole (see page 204) that can be worn in a shoe under the foot, where it measures the pressure between the shoe and the foot. With this device, biomechanists can determine the extent that each part of the insole plays in a specific activity. This information can then be used to determine which bones will sustain most of the load while the foot is in contact with the ground. Knowing the amount of force that each bone receives allows the sport shoe manufacturer to adjust the amount of support and cushion in the shoe to best support the foot and reduce the chance of injury.

Currently, most of the biomechanical shoe research is directed toward the cushioning and stability of the sport shoe. Some other important considerations in shoe design are the flexibility and density of the sole as well as the weight, durability, and breatheability of the upper part of the shoe. Using the techniques previously described, biomechanists analyze the demands of a specific sport (e.g., basketball or volleyball) in relation to the shoes that are designed for that sport. This research has dramatically improved the design of all sport shoes.

Examples of biomechanists' involvement with the development of exercise equipment for improving strength and endurance can be found in stairstepping machines and exercise bicycles. Biomechanists evaluated posture and the ability to produce force, while reducing the potential for injury, on each of these devices. The result has been the evolution of both the stair-stepping machine and the exercise bicycle. These devices are now more comfortable and easier to use, while still providing safe and effective resistance for improving strength and endurance.

Biomechanists also have been involved in the development and testing of protective devices (e.g., eyeguards and football helmets and pads) and in the development and testing of sport equipment (e.g., golf clubs, ice skates, and tennis racquets). These devices help athletes improve performance.

An example of the use of biomechanics to improve sport performance can be found in the golf-swing analysis now available from many professionals who teach golf. With a high-speed video camera and speed-measuring device, the golf instructor can determine a player's position and movement throughout the golf swing. The speed and path of the golf club head, as well as the speed and path of the ball after contact, can also be determined. These data provide the instructor with the information necessary to describe the player's actions that result in the path of the golf ball. By adjusting the player's actions, the instructor can alter the path of the ball and perhaps improve performance. This type of analysis can be helpful to the beginner as well as the highly skilled player.

Rehabilitative Biomechanics

Biomechanical research also focused on studying the movement patterns of injured and disabled people. Biomechanists analyze the movement changes after injury and determine the specific movement abnormality. This information is crucial for clinicians, especially physical therapists and athletic trainers, when developing an appropriate rehabilitation protocol for individuals to relearn the motor skills after an injury. Biomechanical research in the area of rehabilitative biomechanics led to the development of sound exercises and exercise machines to train injured individuals back to pre-injury functioning; the development of supplement devices such as canes, crutches, walkers, and orthotics; and the development of substitution devices such as prostheses and wheelchairs. By using objective biomechanical measurements obtained through equipment such as goniometers and force transducers, biomechanists can determine the effectiveness of those devices and provide professional opinions to help physicians and therapists improve their usage.

An example of rehabilitative biomechanics is the study of the effects of peripheral arterial disease (PAD) on gait patterns (Chen et al., 2006; Huisinga, Piponos, Stergiou, & Johanning, 2010). PAD is a progressive disease that limits patients' ambulation due to intermittent pain in the leg muscles and cramping pain induced by movement (i.e., walking). Rehabilitative biomechanists can determine specific abnormalities in the joint movement patterns of the patients' legs. Then the effect of pharmacotherapy, conservative treatment, and surgical treatment can be evaluated by biomechanically monitoring these abnormalities. Multiple sclerosis patients are another population that can benefit from rehabilitative biomechanics. A progressive neurological disorder that results in a high incidence of gait disturbance, multiple sclerosis can be studied with biomechanics to determine specific gait impairments and to develop rehabilitation techniques that address the problems identified (Wurdeman, Huisinga, Filipi, & Stergiou, 2010).

Occupational Biomechanics

Biomechanical research often focuses on providing a safer and more efficient environment for the worker. The development of better safety equipment (e.g., helmets, shin guards, footwear) for protecting the body from the effects of falling or colliding with other objects is an important area of biomechanical research. In addition, the development of safer or more mechanically efficient tools, improvement in the design of transportation modules (e.g., airplanes, spacecrafts, trains, boats, automobiles), and decreased occupational injury are major contributions by biomechanists to various work environments.

As with other areas of biomechanical inquiry, biomechanists are also involved with legal cases involving industrial design and safety. For example, a biomechanist was asked to determine the factors that contributed to two nailgun accidents. The issues assessed included the adequacy of the design relative to human performance capabilities, expected use patterns, and the use and effect of warnings. The adequacy of machine design relative to safety when cleaning and operating the nail-gun was also a concern. Site and product examination, coupled with an analysis of human perceptions and expectations, suggested that the design was unsafe and a contributing cause of the accidents.

Product liability is another area in which biomechanists are asked to testify. Product evaluation and design effects on a performance injury are common issues in this area. For example, a woman playing softball severely injured her ankle when she slid while wearing an improperly designed shoe. The analysis demonstrated within a reasonable degree of biomechanical probability that the specific injuries were caused by the improper shoe design even though the slide was properly executed. In another case, the possible causes of a knee injury while playing golf were evaluated to determine the likelihood that poorly designed shoes were the cause (see www.hpwbiomechanics.com).

To reduce the incidence of occupational injury, biomechanists objectively evaluate working performance and develop optimal environments. For example, biomechanists have examined proficiency in robotic assistive surgery by measuring the joint range of motion and the muscle activation of the surgeons’ upper extremities during surgical procedure, (Judkins, Oleynikov, & Stergiou, 2009; Narazaki, Oleynikov, & Stergiou, 2006). These biomechanical measurements were used to develop an advanced surgical training program that optimizes surgeons' performance and minimizes tissue injury in a variety of surgical operations.

Forensic Biomechanics

Biomechanical research in this area is related to questions that arise in legal situations. Forensic biomechanists are invited to analyze evidence, clarify some of the most important issues, and facilitate the decisions of the jury. In most cases, biomechanists provide forensic investigations, technical reports, and expert testimony for a broad range of human performance-related incidents involving personal injury. The work of an expert witness always involves a human element or component interacting with various aspects of the environment. Most accidents typically involve an initial perceptual component, some form of expectation, and an action, which typically results in a biomechanical consequence. Also, there is often a need to match the resulting injuries with the actions.

For example, a biomechanist was asked to determine which of two occupants involved in a fatal auto accident was driving. Vehicle and site inspection data and an evaluation of the occupants' injuries were incorporated in the analysis to show that the driver was likely to be thrown from the auto during the accident's progress. In another case, an analysis and evaluation was done to determine the potential effects of lap belt and shoulder harness restraint systems on the injuries suffered by a passenger in an auto accident. Various forces on the spine were calculated to demonstrate the differential effects of the restraint systems and body positions. A number of cases involving lowspeed, rear-end impacts were also evaluated. Such case evaluations typically use a computer simulation program that estimates movement and forces of the head and neck. Investigations of the possible causes of auto accidents involving unexpected acceleration, which involves the human elements of perception and expectation regarding the function of the gas and brake pedals, also have been done. In addition, biomechanical analyses were conducted on the system designs to determine their adequacy (www.hpwbiomechanics.com).

In another case, the biomechanist was asked to determine the possible causes of a fall while descending a stairway. The primary issue for investigation was whether small deviations in riser heights and tread slopes could sufficiently alter performance such that a fall resulted. The biomechanical evaluation, however, suggested the fall resulted from other factors. Evaluations also have been done to determine whether poorly designed and constructed shoes can cause a slipand-fall accident. The ensuing site and product examination verified that the shoe construction was such that, over time, deterioration took place, resulting in a hazardous product when worn on selected surfaces. A fall from a kitchen stool being used on a linoleum surface was also investigated. A biomechanical evaluation of the stool–surface system showed that a typical movement by the user was sufficient to cause the stool to slide, resulting in the fall.

Technology and Research Tools

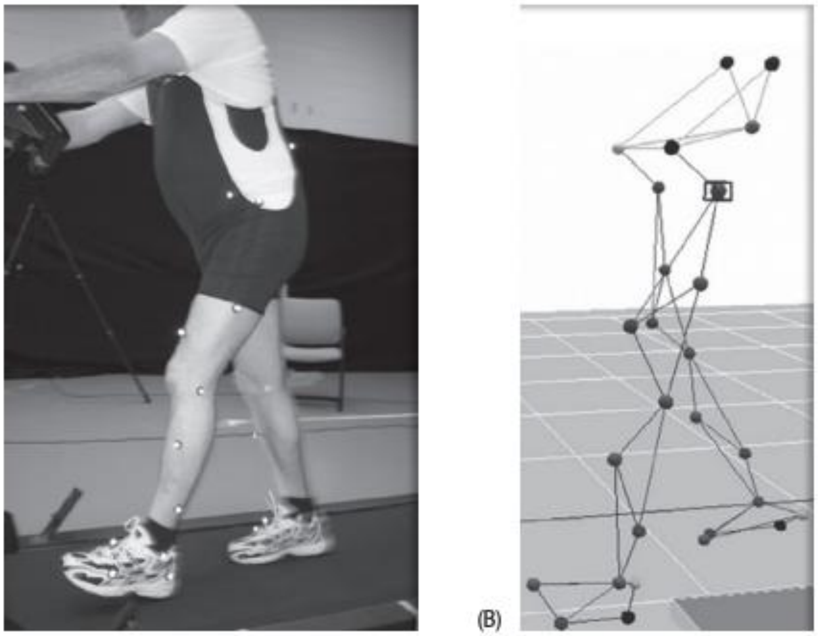
Biomechanists use many pieces of equipment to measure and record time, motion, and force. These devices are essential for the biomechanist to collect and analyze human movement (Rodgers & Cavanagh, 1984).

To record time and motion, timing devices (e.g., watches, digital clocks) and motion image recording methods and devices (e.g., cinematography, videography, digital imaging, magnetic resonance imaging, goniometers) are used to provide temporal and kinematic data. Temporal and kinematic data can also be combined with force measurements quantified by force platforms, pressure insoles, accelerometers, and electromyography to obtain kinetic data such as joint movements and powers. Furthermore, this information can be integrated with modeling and simulation techniques to predict performance.

When body movement is captured by the motion recording device, the recorded images of reflective skin markers are converted into spatial coordinates (see Exhibit 9.3A). From the coordinates of the digitized markers, the displacements, velocities, and accelerations of each recorded moving body segment can be calculated (Exhibit 9.3B). Motion recording devices use optical lenses to capture body motion and provide permanent recorded images of movement that can be evaluated with more precision than perception with the naked eye alone (Exhibit 9.4). The human eye operates at a speed of only 12 frames per second. Therefore, many activities, such as the contact of the foot with the ground while running, happen so quickly that they must be analyzed by specialized equipment that can capture the activity in many more frames per second. In this way, a biomechanist can more precisely analyze such things as foot injuries that may occur while running.

Photographs provide permanent still images of one instant in a performance that can then be analyzed and described. A photograph can also be used to record the location of equipment used to collect research data. A 35-mm camera with a variable focal length lens and adjustable shutter speed and aperture provides the most flexibility when photographing a performance or the data collection environment.

Exhibit 9.3: Capturing body movement.



(A) (B)

(A) Reflective skin markers are placed in various anatomical positions.
(B) Body segment locations are calculated as a model by using the information gathered with the reflective skin markers.

Exhibit 9.4: Optical recording devices in a biomechanics laboratory, such as highspeed digital optoelectronic cameras provide permanent recorded digital images for evaluation.

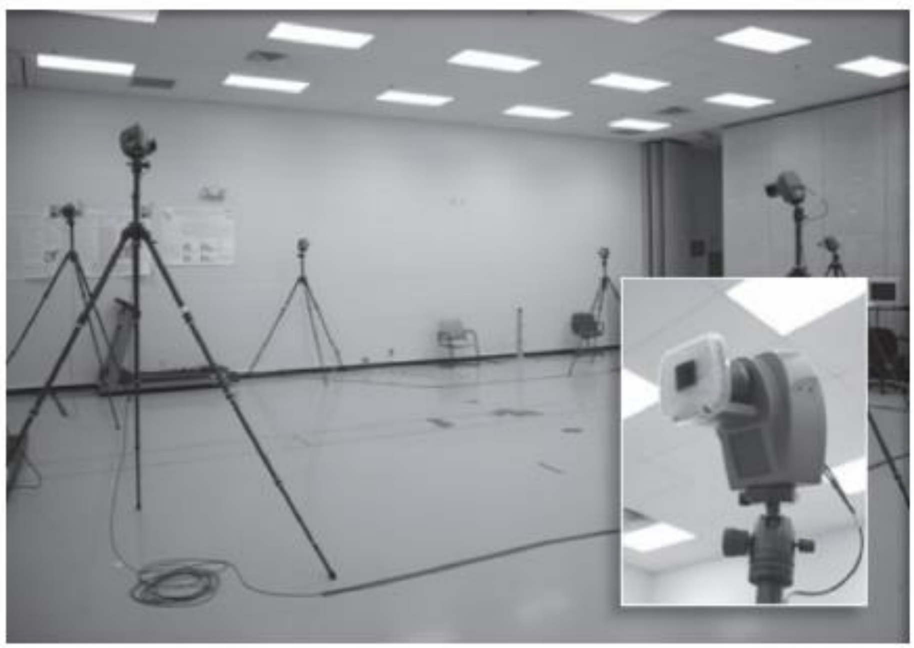


Photo courtesy of Motion Analysis Corp., Santa Rosa, California.

Cinematography provides a sequence of images that can be displayed as a motion picture or be viewed one by one. Filming can be done at nearly any speed, from less than one frame per second to more than five million frames per second. Filming at high frame rates allows motion that is too fast to see with the naked eye to be captured and viewed in slow motion or as individual images. Although rarely used today, the 16-

millimeter film cameras used in cinematography with variable focal length lenses and adjustable shutter speeds and apertures, capable of adjustable frame rates of up to 500 frames per second, provide the most flexibility in data collection. Videography also provides a sequence of images that can be displayed as a motion picture or viewed individually.

Videography has most of the features of cinematography, with the convenience of instant viewing and the ability to reuse the videotape. The most common videotape cameras and recorders capture images at 30 frames per second using variable focal length lenses and adjustable shutter speeds and apertures. Today, the videotape cameras have evolved into high-speed digital optoelectronic systems that directly capture the digital images of movement described by the trajectories of reflective skin markers (see Exhibit 9.3A). The digital trajectories of the markers are then directly stored into a computer hard drive.

Thus, videotapes are no longer needed in a digital optoelectronic motion capture system. Today's motion capture systems are mostly of two types: passive and active systems. Passive motion capture systems use markers coated with a reflective material to reflect light from the cameras. Active motion capture systems use active markers with light-emitting diodes (LEDs); rather than reflecting light back to the camera, the active makers are powered to emit their own light and their relative positions are tracked by illuminating the LEDs (see Exhibit 9.5).

Exhibit 9.5: An active motion capture system in a biomechanics laboratory tracks the relative position of the markers by illuminating LEDs. Three LEDs are attached on a rigid body (see insert at bottom left).

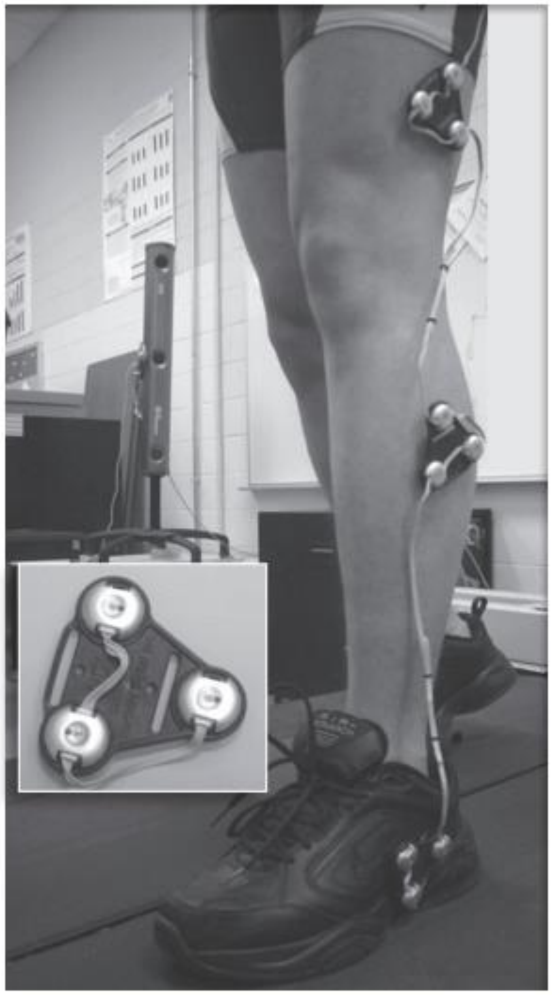


Photo courtesy of Northern Digital, Inc., Ontario, Canada.

For a more comprehensive biomechanics analysis, a motion capture system can be used with other equipment, such as an instrumented treadmill (discussed later; refer to Exhibit 9.11) to evaluate both kinematics and kinetics during walking. Motion of the leg can be captured by either an active or a passive marker of a motion capture system, while forces from the ground can be measured and captured by the force plate embedded in the instrumented treadmill. By combining the kinematic data from the motion capture system with kinetic data from the instrumented treadmill, the neuromuscular responses and their contributions in the form of joint movements and powers can be evaluated during walking.

Magnetic resonance imaging (MRI) provides a computer-generated two-dimensional image of any body part (discussed in earlier chapters). After the two-dimensional image is acquired, it is manipulated so that it can be viewed on a video monitor and reconstructed into a three-dimensional image. MRI provides a noninvasive means of viewing the structures under the skin. This allows for a better evaluation of an injury or a muscle adaptation to training.

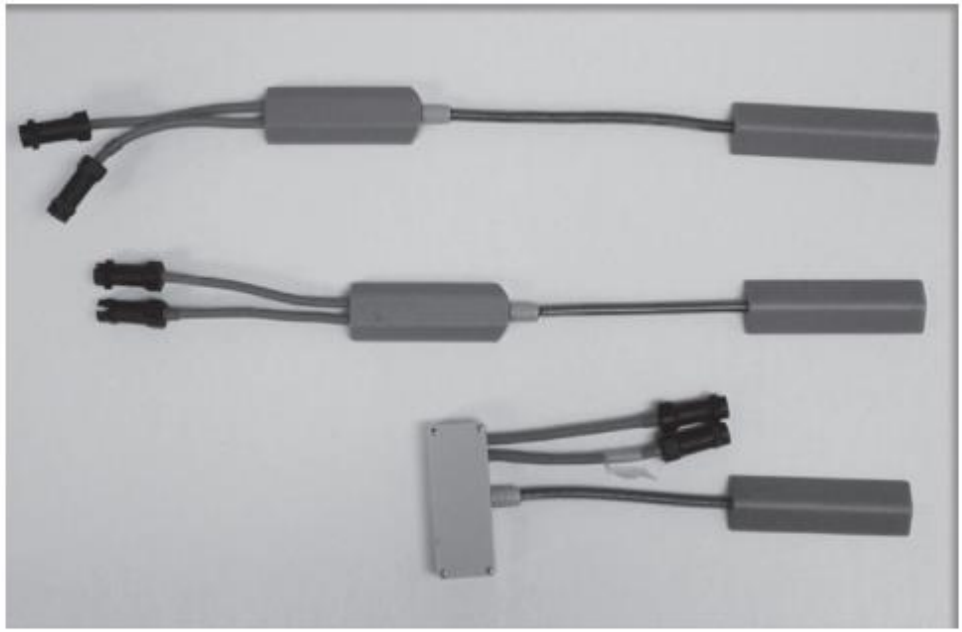
Goniometers provide kinematic data on joint positioning. They are used to measure static positions of limb segments with respect to a joint axis (Exhibit 9.6). An *electrogoniometer* is a goniometer with a *potentiometer* (variable resistor) at its axis of rotation. The electrogoniometer provides an indication of joint position during movement and can be calibrated to determine speed of movement. The device is most often attached to the body with the axis of the potentiometer aligned with the long axis of segments. The electrogoniometer provides an output voltage, proportional to the joint angle, that can be measured, scaled, and recorded. This information can be used to assess flexibility for diagnosis, rehabilitation, and exercise prescription.

When kinematic data of movement are measured, they can be combined with data from force platforms, pressure insoles, accelerometers, and **electromyography (EMG)** to provide even more details regarding body motion.

Dynamography provides kinetic or force data. An example of a dynamographic device is a force platform with built-in force transducers that provide electrical signals proportional to the components of force acting on it. A transducer is a measuring device that converts one form of energy into another. An electrical displacement transducer, for example, converts kinetic energy from movement into electrical energy. Force transducers used in a force platform are usually either strain gauges, which change their electrical resistance with strain, or piezoelectric elements, which generate a charge when stressed. The electrical energy can then be measured and recorded as an indication of the amount of force inserted. The most common use of a force platform is to measure the three orthogonal components of ground reaction forces (GRFs) in vertical (F_z), anterior–posterior (F_y), and medial–lateral (F_x) between the foot and the floor during locomotor activities (refer back to Exhibit 9.2). Force platforms can be used to assess the forces generated during contact with the ground in a variety of activities such as running, walking, jumping, landing, and hopping.

Exhibit 9.6: Static positions of limb segments can be measured by electrogoniometers such as those in this photo.

Photo courtesy of Biometrics Ltd, Gwent, UK.



Another example of a dynamographic device is a **pressure insole.** The pressure insole consists of a matrix of elements that are small-force transducers of a known area (see Exhibit 9.7). If the area is sufficiently small, the force on each element can be considered uniformly distributed, and thus, an estimate of pressure is available. This device gives more information concerning pressure distribution under the foot than a force platform because the pressure acting on individual anatomical foot regions can be measured, rather than just the resultant force acting on an entire region; for example, the whole foot. This information is especially important in shoe design, diabetic foot evaluation, and pathological gait.

An **accelerometer** is an electronic device that measures acceleration forces (see Exhibit 9.8). It usually consists of an inertial mass that exerts a force against an element, such as a beam, whose resulting strain is then measured. Because we know from Newton that force is the product of mass and acceleration (the change in how fast an object is moving), and that mass is a constant, we can estimate forces if we know accelerations. Therefore, accelerometers are used when other force measurement devices cannot be. For example, it is very difficult to use a force platform on a treadmill; however, an accelerometer can provide information about the forces generated during treadmill running.

Exhibit 9.7: Pressure distribution under a foot can be measured by a pressure insole. The pressure insole consists of a matrix of small-force transducers (top left of the figure).

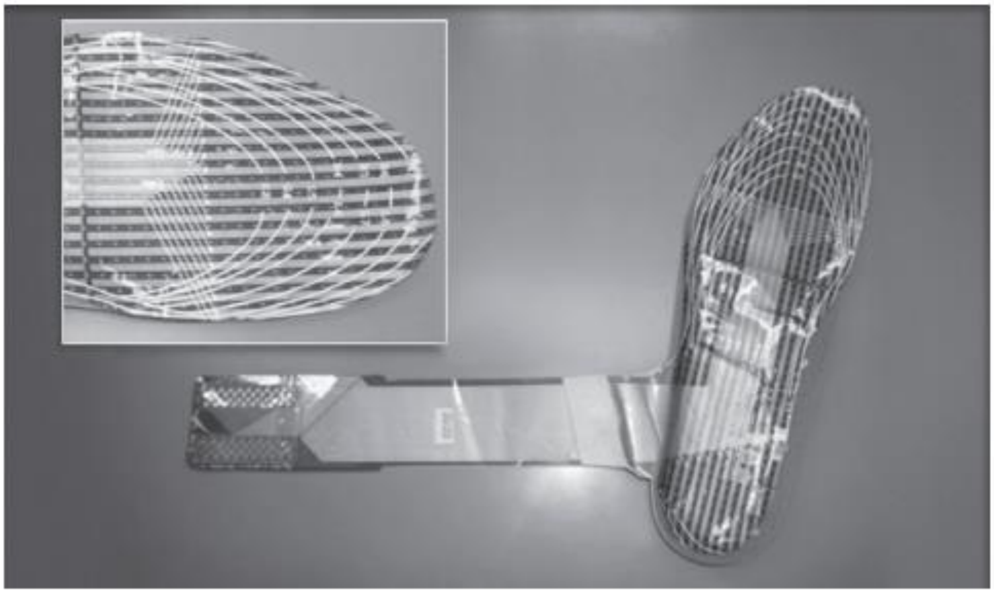


Photo courtesy of Tekscan, Inc., South Boston, MA.

Exhibit 9.8: Motion acceleration can be measured by an accelerometer.

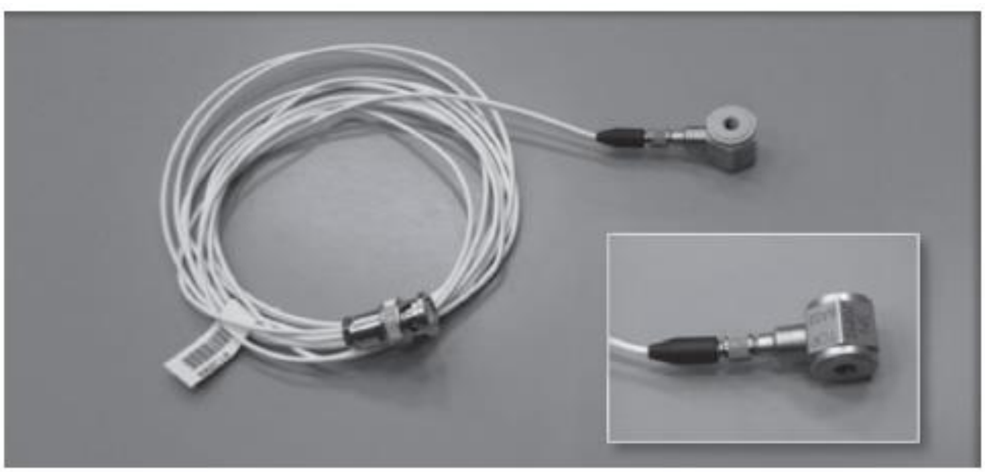


Photo courtesy of PCB Piezotronics, Inc., Depew, NY.

As mentioned in Chapter 5, electromyography provides data on muscle activity (see Exhibit 9.9). An electromyograph records electrical changes that occur in a muscle during or immediately before contraction. This electrical activity can be captured, amplified, filtered, and recorded as an indication of muscle activity during a performance.

Modeling and **simulations** provide a prediction of kinematic and kinetic data. These techniques are used to provide insight into specific activities or events. For example, muscles can be modeled as springs and bones as rigid bodies and then internal forces can be predicted. Such information can be valuable for estimating forces, such as those acting at the lower back during lifting. To fully understand the mechanism of human movement, more complex and sophisticated biomechanical instruments are now being utilized in biomechanics laboratories. For example, staircases (Exhibit 9.10) and treadmills (Exhibit 9.11) instrumented with force platforms provide biomechanists unique abilities to investigate stair negotiation and generation of forces during locomotion, respectively.

Exhibit 9.9: Muscle activity can be measured by surface EMG. This EMG system consists of 16 electrodes; one of them is shown at the bottom left of the figure.

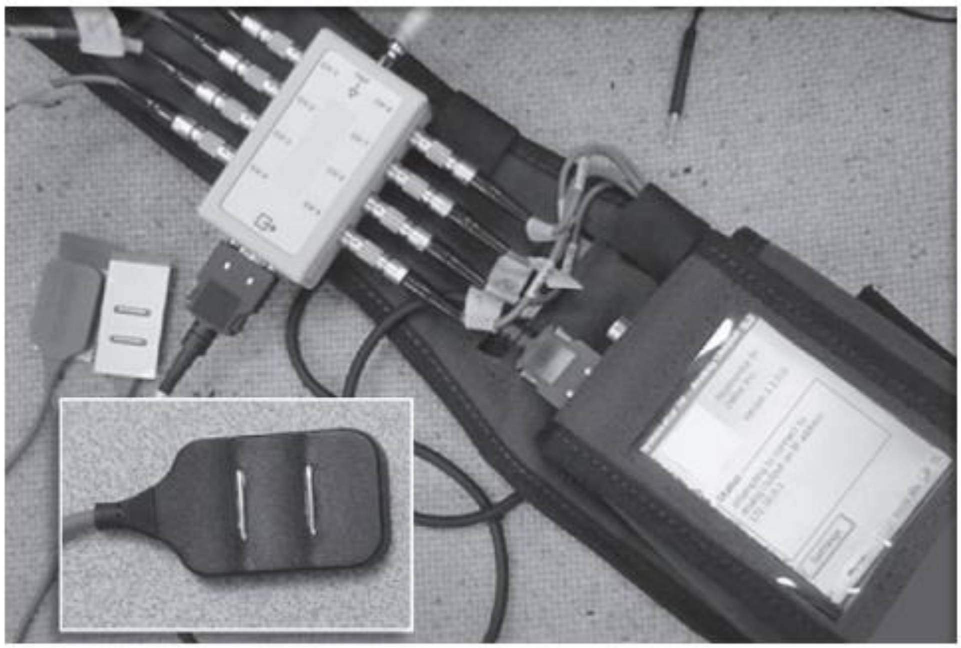
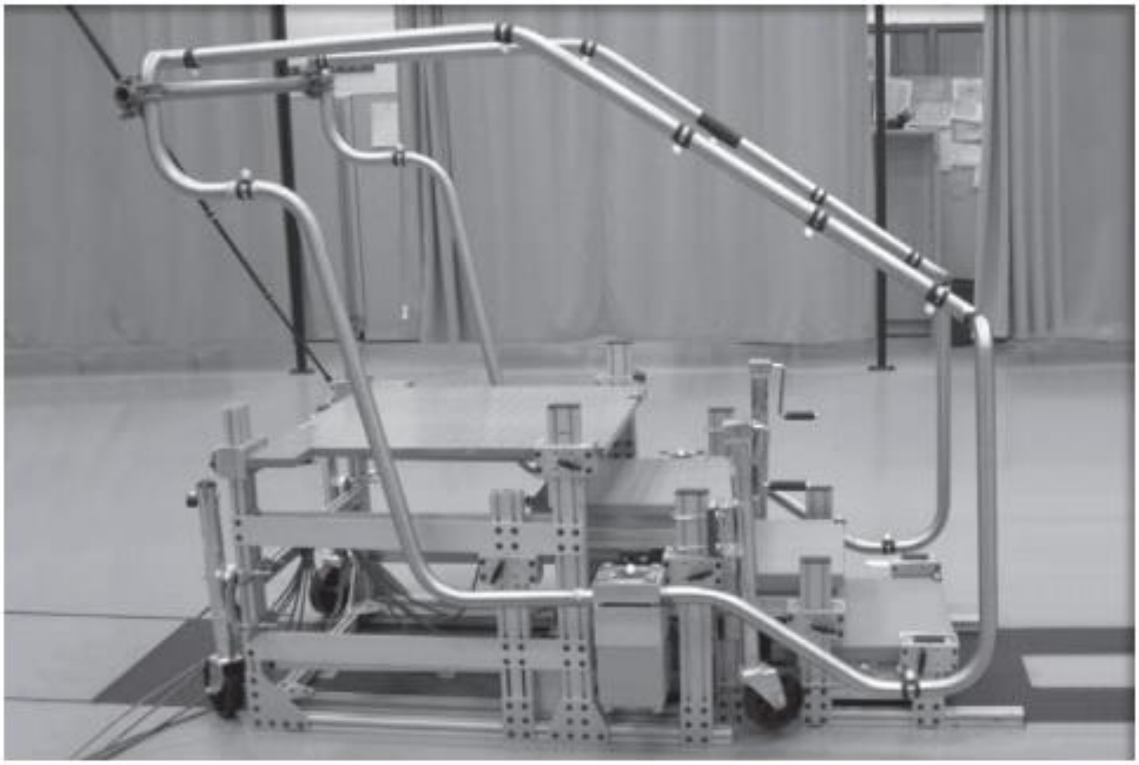


Photo courtesy of Delsys Inc., Boston, MA.

An **instrumented staircase** typically is equipped with multiple force platforms. For example, in Exhibit 9.10, a force platform is embedded under the first three steps, and an additional force platform is connected to the handrail structure. An instrumented staircase can accurately measure the amount of force applied on each step during stair ascent and descent and can detect the usage of handrails during stair negotiation. Combining the force (kinetic) data from the instrumented staircase with kinematic data from motion recording devices, the neuromuscular responses and their contributions in the form of joint movements and powers can be estimated. In this fashion biomechanists can fully understand the mechanism of human stair negotiation and help physicians and therapists to develop strategies for patients to regain their ability to climb stairs.

Exhibit 9.10: A custom instrumented staircase with multiple force platforms.



An **instrumented treadmill** has force platforms embedded below the belt. In Exhibit 9.11, a custom split-belt instrumented treadmill has two large force platforms under its dual belt design. It can allow biomechanists to measure the amount of force applied while walking or running on the treadmill. An additional unique feature of this device is its split-belt design, which can provide a different speed for each belt or even two different directions. It creates a more challenging environment for studying human locomotion. Instrumented treadmills allow biomechanists to conduct advanced biomechanical research study, such as locomotion adaptation and asymmetrical walking.

Exhibit 9.11: The amount of force during locomotion can be measured by a split-belt instrumented treadmill.

Photo courtesy of Bertec Corporation, Columbus, OH.

Computerized dynamic posturography is used to measure the control of posture and balance in upright stance. To study balance, biomechanists can use a device such as the SMART Balance Master (Exhibit 9.12) to measure body sway in a standing position. This sophisticated instrument provides different research protocols that allow biomechanists to study the contribution of different sensory systems (visual, vestibular, and somatosensory) in maintaining postural stability. The embedded force platform with rotation and translation capabilities provides either a stable or unstable support surface and measures the amount of force exerted by the participant. The movable visual surround provides an additional complexity and challenge for participants regarding how they can maintain their postural stability in a stable or dynamic visual environment.

Exhibit 9.12: Body sway can be measured by the SMART Balance Master.

Photo courtesy of NeuroCom, a division of Natus: Clackmas, OR

Educational Preparation

Because of the diversity of the areas related to the field of biomechanics, a broad range of knowledge is required to be successful. For example, the entrance requirements for the doctoral program in biomechanics at the University of Calgary include course work in mechanics (statics and dynamics), mathematics (calculus, linear algebra, and differential equations), computers (competence in one language), measuring techniques (force measuring systems, accelerometers, electromyography, videography, goniometers), and gross anatomy and mechanical properties of human tissues (bone, cartilage, joints, tendons, muscles). Course requirements for entry into the doctoral program at the University of Nebraska at Omaha include study in the areas of mathematics, computer science, physics, and motor control and learning.

Although the general course requirements for entry into a doctoral program in biomechanics and those required to complete a doctoral program are similar from one university to another, the courses and activities are specific to each university. The courses are often tied to the focus of the research being conducted at the particular university's biomechanics laboratory. Because biomechanics is a broad and diverse field, there should be variety in the training of the individuals working in the field. The training for someone working in rehabilitative biomechanics will be distinctly different from that of someone working in sport biomechanics or industrial biomechanics.

Therefore, if there is a question about who is the best trained in the field, the answer is it depends on the job requirements.

Employment Opportunities

Employment opportunities in biomechanics are extremely varied as a result of the great variety of applications related to biomechanics. The opportunities can be arbitrarily classified into academic, postdoctoral, research and graduate assistant, and industry and government positions. An indication of the type and great quantity of the positions available can be found at the Biomechanics website.

Biomechanics: www.uni-essen.de/˜qpd800.WSITECOPY.html

Professional Associations

Several professional associations in the field of biomechanics allow biomechanists to meet and discuss specific topical areas. For more information about these organizations, visit their respective websites.

The American Society of Biomechanics (ASB) was founded in 1977 and has about 500 members today. The purpose of ASB is to provide a forum for the exchange of information and ideas among researchers. The society is affiliated with the *Journal of Biomechanics*. Meetings are held on an annual basis throughout the United States.

The Canadian Society of Biomechanics (CSB) was founded in 1973. Its purpose is similar to the ASB's; however, the CSB has successfully expanded internationally, as evidenced by the large participation of international scientists. The meetings are held biannually.

The International Society of Biomechanics (ISB) was founded in 1973 and has about 1,000 members today. The purpose of the ISB is to promote the study of all areas of biomechanics at the international level, although special emphasis is given to the biomechanics of human movement. The ISB meetings are held on a biannual basis.

The International Society of Biomechanics in Sports (ISBS) was set up to provide a forum for the exchange of ideas between sport biomechanics researchers, coaches, and teachers; to bridge the gap between researchers and practitioners; and to gather and disseminate information and materials on biomechanics in sports. The first meeting took place in 1982, and a constitution was developed by 1983. Meetings are held on an annual basis.

ASB: www.asbweb.org

CSB: www.csb-scb.com

ISB: www.isbweb.org/

ISBS: www.isbs.org/

Prominent Journals and Related Publications

Because of the breadth of scientific inquiry in the field of biomechanics, several journals publish articles related to the field. Those in which scientific articles are most commonly found follow.

Primary Journals

Clinical Biomechanics

Journal of Applied Biomechanics

Journal of Biomechanics

Related Publications

American Journal of Sports Medicine

British Journal of Sports Medicine

Ergonomics

Foot and Ankle International

Gait & Posture

Human Factors

Human Movement Science

International Journal of Sports Medicine

Journal of Bone and Joint Surgery

Journal of Electromyography and Kinesiology

Journal of Human Movement Studies

Journal of Orthopaedic and Sports Physical Therapy

Journal of Orthopaedic Research

Journal of Sports Medicine and Physical Fitness

Journal of Strength and Conditioning Research

Journal of the American Podiatric Medical Association

Medicine & Science in Sport & Exercise

Medicine, Exercise, Nutrition and Health

Physical Therapy

Research Quarterly for Exercise and Sport

Strength and Conditioning Research

The biomch-L newsgroup is an e-mail discussion group for biomechanics and human and animal movement science. To subscribe, and for more information on the resources available on biomch-L, visit the site at left.

Boxes 9.1 and 9.2 are typical abstracts presented at the American Society of Biomechanics scientific conference.

biomch-L: http://biomch-l.isbweb.org/forum.php

Future Directions

In the future, biomechanics will be applied across many professional domains to understand fundamental movement in sports, exercise, medicine, robotics, biology, gaming, and occupational science. Applications of biomechanical analysis utilizing various measurements and tools will examine human movement from infants to elderly and from healthy to pathological populations. New and innovative analyses in biomechanics—for example, nonlinear analysis for human movement variability (Stergiou, 2004)—have been developed to study human performance. By using advanced mathematical algorithms, biomechanists can understand human movement variability in a nonlinear fashion. Such approaches will expand our understanding of human movement in many biomechanical applications, especially in clinical areas.

Biomechanics will also be combined with other disciplines in exercise science to provide a complete picture of how biomechanics influences human movement (Hamill, 2007). One such example is the interaction of biomechanics and exercise physiology in the physiological cost of running. Interestingly, runners' preferred speed represents the most efficient speed, as noted by the lowest oxygen consumption. Running faster or slower than the preferred speed results in increases in oxygen consumption (Hamill, 2007). Integrating multiple disciplines within exercise science will make the study of biomechanics more relevant for students and provide valuable insights into biomechanics research results.

Box 9.1: An abstract presented at the American Society of Biomechanics.

Myers, S. A., Johanning, J. M., Pipinos, I. I., & Stergiou, N. (2010). Gait variability patterns are altered in healthy young individuals during the acute reperfusion phase of ischemia-reperfusion. Journal of Surgical Research, 164(1), 6-12.

INTRODUCTION

Peripheral arterial disease (PAD) is a localized manifestation of systemic atherosclerosis, affecting the leg arteries and resulting in significantly reduced blood to the lower extremities. PAD affects eight to twelve million individuals in the US, with the majority of these being elderly[1]. Intermittent claudication, a cramping pain occurring in the lower extremity muscles with physical activity and relieved with rest, is the most common symptom of PAD. PAD has been shown to lead to poor health outcomes, immobility, physical dependence, and an increased risk for falling. Previous research in our laboratory indicates that PAD patients have altered gait variability patterns prior to the onset of claudication pain[2]. However, the specific mechanisms that contribute to these alterations in PAD patients are unclear. Potential mechanisms include insufficient blood flow, underlying neural and muscular abnormalities of the lower extremity, and systemic co-morbidities[3]. Therefore, our study sought to isolate and determine the impact of reduced blood flow on gait parameters by evaluating lower extremity gait variability before and after induced lower extremity vascular occlusion in healthy younger and older individuals. We hypothesized that a decrease in blood flow would result in significant gait variability alterations compared to baseline gait. Additionally, we hypothesize that age would augment the changes in gait variability following the vascular occlusion.

METHODS

Thirty healthy young subjects (Age: 22.8 ± 4.2 years) and 28 healthy older subjects (Age: 60.2 ± 8.2 years) walked on a treadmill while kinematics (60 Hz) were recorded using a Motion Analysis system. Participants walked at their self-selected speed for 3 minutes (Baseline). Next, vascular occlusion was induced by thigh cuffs placed bilaterally on the upper thighs and inflated to 200 mmHg for three minutes while subjects were standing. After three minutes of occlusion, the thigh cuffs were removed and the subjects immediately began walking on the treadmill (Post Occlusion). Relative joint angles of the ankle, knee, and hip were calculated for thirty strides from the Baseline and Post Occlusion conditions. Gait variability was assessed from the unfiltered joint angles using the largest Lyapunov exponent (LyE) and approximate entropy (ApEn). The LyE is a measure of the rate of divergence of neighbored state-space trajectories and it estimates the sensitivity of the locomotor system to perturbations. The ApEn quantifies the regularity or predictability of a time series. The Chaos Data Analyzer[4] was used to calculate the LyE. ApEn was computed using algorithms written by Pincus[5] implemented in Matlab. Gait variability was compared using a 2 X 2 ANOVA (Groups: Younger vs. Older, Conditions: Baseline vs. Post Occlusion). When a significant interaction was identified, independent t-tests were used for post-hoc analysis to identify significant differences between the group/condition combinations.

RESULTS AND DISCUSSION

There was a significant effect of condition for all variables tested. Specifically, the LyE and ApEn values were significantly higher Post Occlusion compared to the Baseline condition. There was also a significant effect of group, with the ApEn at the hip being significantly higher in the older group. Additionally, there was a significant interaction for the ApEn at the ankle. Specifically, the younger group had significantly higher values Post Occlusion as compared with the older and younger groups at baseline. Also, the older group Post Occlusion had significantly higher ApEn at the ankle compared with the younger group at baseline.

Our results demonstrate significant gait variability alterations for all lower extremity joints Post Occlusion based on the LyE and ApEn in both healthy younger and healthy older individuals. The direction of differences are similar to a previous study comparing gait variability of healthy matched controls and patients with PAD[2]. Specifically, the differences indicated an increase in noise and irregularity while walking after vascular occlusion and may reflect a diminished capacity of the neuromuscular system to achieve a stable gait. However, direct comparison of the magnitude of change in LyE values show that interruption of blood flow does not account for the total amount of changes in gait variability exhibited by patients with PAD. To compare values directly, the mean differences from the healthy baseline condition (younger and older combined means) were expressed as percentage change averaged across all joints for the Post Occlusion condition and for PAD patients as compared to the healthy baseline condition. The Post Occlusion condition had an average increase in LyE values of 11.5%, while the PAD patients had an average increase of 41.3%[2]. Thus, our findings support the idea that interruption of blood flow results in significant gait alterations in otherwise healthy individuals, but patients with PAD experience additional alterations in variability that are likely due to underlying cellular abnormalitites in the lower extremity muscles and nerves that have been demonstrated in these patients[6]. As a result of age, there was only one significant group effect of the six variables tested, while restricted blood flow caused significant differences in all variables (Table 1). This suggests that altered blood flow status, as seen in PAD, is a greater determinant of gait function than age.

SUMMARY

Collectively, our study shows that reduced blood flow, in the absence of pathology significantly alters gait variability patterns. However, the change in the gait variability patterns was not as severe as previously documented in symptomatic patients with PAD during pain free ambulation. These results support the hypothesis that additional neuromuscular problems in the lower extremities of patients with PAD contribute to gait alterations in these patients. Nevertheless, blood flow is one mechanism contributing to altered gait variability patterns in patients with PAD and individuals with risk factors for PAD should be screened and treated immediately to prevent potential mobility problems (i.e. falls) and the development of more severe pathophysiological changes that have been observed in symptomatic PAD patients.

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ACKNOWLEDGEMENTS

American Society of Biomechanics Graduate Student Grant-in-Aid, AAHPERD Graduate Student Grant-in-Aid, the Nebraska Research Initiative, and NIH (K25HD047194 and F31AG032788).

Table 1: Group means for the largest Lyapunov Exponent (LyE) and the approximate entropy (ApEn) for younger (Y) and older (O) groups during the Baseline (B) and Post Occlusion (PO) conditions. All values are reported mean ± standard deviation.

Condition	Ankle	Knee	Hip
LyE			
Y-B	.069 ± 0.02	.066 ± 0.02	.066 ± 0.02
Y-PO	.088 ± 0.02	.081 ± 0.02	.076 ± 0.02
O-B	.076 ± 0.02	.074 ± 0.02	.071 ± 0.02
O-PO	.080 ± 0.01	.084 ± 0.02	.080 ± 0.02
Significance	*	*	*
ApEn			
Y-B	.712 ± 0.13	.431 ± 0.08	.307 ± 0.06
Y-PO	.858 ± 0.17	.504 ± 0.08	.374 ± 0.08
O-B	.762 ± 0.14	.482 ± 0.08	.349 ± 0.08
O-PO	.822 ± 0.13	.527 ± 0.09	.406 ± 0.09
Significance	*, ‡, §, ‖, ¶	*	*

* $p<0.05$, significant difference, B vs. PO
‡ $p<0.05$, significant difference, Y vs. O
§ $p<0.05$, significant interaction, Y-B vs. O-PO
‖ $p<0.05$, significant interaction, Y-B vs. Y-PO
¶ $p<0.05$, significant interaction, Y- PO vs. O-B

Box 9.2: An abstract presented at the American Society of Biomechanics.

Huisinga, J. M., & Stergiou, N. (2011). Persons with multiple sclerosis show altered joint kinetics during walking after participating in elliptical exercise. Journal of Applied Biomechanics. Epub Oct. 3.

INTRODUCTION

Multiple Sclerosis is a progressive neurological disease that is associated with a wide range of symptoms including motor weakness, increased falls, exaggerated fatigue, poor balance, spasticity, vision problems, heat sensitivity, decreased physical activity, cognitive deficits, and depression [1]. Exercise has been shown to improve overall quality of life and mobility in MS patients [2, 3]. However, the most effective exercise modality to improve mobility in MS patients is unknown. In order to determine whether gait-simulating exercise training is a viable treatment option for MS patients, biomechanical analysis of gait is necessary to quantitatively determine whether changes in gait mechanics occurs as a result of the training. Therefore, the purpose of this study was to determine the effect of a short-term aerobic, gait-simulating exercise intervention on the functional movement status of MS patients. It was hypothesized that the training would result in joint torques and powers that were closer to those of healthy controls.

METHODS AND PROCEDURES

Eighteen MS patients (46.1 ± 10.1 yrs; EDSS 2.4 ± 0.7) and 18 healthy matched controls (40.7 ± 11.3 yrs) walked through a 10 meter walkway at their self-selected walking pace, while kinetics and kinematics were collected for 10 trials with a Kistler force plate (600Hz) and an 8-camera Motion Analysis system (60 Hz). Data collection was performed on the MS patients before and after individuals participated in a total of 15 exercise session over a period of six weeks. The exercise modality used by all patients was an elliptical exercise machine which allowed weight-bearing, sagittal plane motion with joint kinematics similar to walking [4]. Each training session consisted of 30 minutes of cumulative exercise. Healthy controls underwent only one gait analysis. Joint torques and powers were calculated from the ground reaction forces and the kinematics for each participant. Maximum flexor and extensor torques and maximum power absorption and generation were identified for the hip, knee, and ankle joints. Paired t-tests were used to compare within MS patients pre- and post-training while a linear mixed model was used to compare outcome measures between MS patients pre- and post-training to healthy controls with velocity as a covariate.

RESULTS

MS patients before training compared to healthy controls exhibited significantly decreased walking velocity, decreased ankle dorsiflexor torque (ADT), decreased ankle plantarflexor torque (APT), decreased knee extensor torque (KET), and decreased hip flexor torque (HFT). In addition MS patients had significantly decreased ankle dorsiflexor power absorption during early stance (A1), decreased ankle plantarflexor power generation during late stance (A2), decreased power absorption at the knee during early stance (K1), decreased hip extensor power generation during early stance (H1), and decreased power absorption of the hip flexors during late stance (H2) (Table 1). Velocity did not have a significant effect on any of these outcome variables. As a result of training, within the MS patients significant increases occurred in APT, HET, A1, A2, and

K1 such that after training, significant differences were not present for these variables between MS patients and controls.

DISCUSSION

Baseline differences between healthy controls and MS patients in joint torques and powers were present prior to the training which indicated that MS patients had significantly decreased flexor and extensor torques and decreased power generation and absorption at all three joints. Following the elliptical exercise training program, significant increases were found for both joint torques and powers such that the MS patients gait parameters moved closer to those of the healthy controls and were no longer significantly different. These results agree with our hypothesis and provide exhilarating support for the use of elliptical exercise training as a rehabilitation tool for MS patients. The significant improvements are occurring during early and late stance specifically. During early stance both ankle (A1) and knee (K1) power absorption are increased which indicates improved weight acceptance during the transition from double to single support. During late stance, there is increased plantarflexor torque (APT) as well as increased power generation at the ankle (A2). During late stance/pre-swing, muscle activity at the ankle enables the leg to enter the swing phase with sufficient propulsion to move the body mass forward. Clinicians refer to gait powered by ankle push-off as using an "ankle strategy", which is thought to be the preferred walking strategy for healthy young adults [5]. Thus, as a result of short term (6 weeks/15 sessions) elliptical training, MS patients seem to have adopted a gait strategy that is similar to the preferred strategy of healthy adults. These findings provide support for the use of an elliptical exercise machine, which is a gait-simulating exercise, as a tool to improve gait mechanics in MS patients in a relatively short amount of time.

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ACKNOWLEDGEMENTS

ASB Grant-In-Aid, the MARS Foundation and the Nebraska Research Initiative.

		Pre-training mean (S.D)	Post-training mean (S.D.)	Control mean (S.D.)	*p*-value pre-con; pre-post; post-con
	Velocity (m/s)	1.11 (0.22)	1.12 (0.24)	1.24 (0.26)	0.023*; 0.212; 0.023*
Joint Torques (N*m/kg)	ADT	-0.277 (0.076)	-0.2844 (0.082)	-0.412 (0.197)	0.013*; 0.571 0.018*
	APT	1.189 (0.140)	1.266 (0.127)	1.341 (0.264)	0.016*; 0.004*; 0.166
	KET	0.542 (0.176)	0.549 (0.188)	0.705 (0.273)	0.020*; 0.333; 0.050*
	KFT	-0.269 (0.145)	-0.274 (0.168)	-0.292 (0.232)	0.833; 0.837; 0.835
	HET	0.611 (0.201)	0.688 (0.158)	0.802 (0.273)	0.123; 0.006*; 0.333
	HFT	-0.781 (0.188)	-0.763 (0.028)	-1.048 (0.306)	0.007*; 0.568; 0.003*
Joint Powers (Watts/kg)	A1	-0.394 (0.035)	-0.477 (0.042)	-0.661 (0.243)	0.002*; 0.003*; 0.060
	A2	2.499 (0.118)	2.81 (0.134)	3.193 (0.869)	0.017*; 0.003*; 0.177
	K1	-0.711 (0.056)	-0.807 (0.072)	-1.068 (0.432)	0.013*; 0.040*; 0.146
	K2	0.457 (0.048)	0.458 (0.051)	0.561 (0.323)	0.430; 0.959; 0.502
	K3	-0.497 (0.038)	-0.480 (0.042)	-1.057 (0.646)	0.153; 0.572; 0.093
	H1	0.410 (0.038)	0.438 (0.032)	0.660 (0.325)	0.036*; 0.396 0.036*
	H2	-0.687 (0.037)	-0.652 (0.039)	-0.990 (0.429)	0.025*; 0.345; 0.008*
	H3	0.490 (0.025)	0.464 (0.025)	0.784 (0.340)	0.108; 0.229; 0.131

Table 1: Joint torque and joint power variables; *Sig ($p < 0.05$).

In the research domain, human movement will be studied to a greater extent using virtual reality. The use of virtual reality takes biomechanical research beyond the laboratory settings to simulating actual environments from which natural human movement responses can be detected. Examples are the VENLab at Brown University, the Medical Virtual Reality Center format at the University of Pittsburgh, and the Nebraska Biomechanics Core Facility at the University of Nebraska at Omaha (Exhibit 9.13).

As new research technologies continue to emerge, wireless transmission will have a major impact on biomechanics. Using wireless systems, research activities normally conducted in laboratories can be expanded outside the laboratory to a larger monitored range of human activity. For example, a wireless biomedical gait device, Gait-O-Gram®, was developed at the Nebraska Biomechanics Core Facility to study human gait variability (Exhibit 9.14).

In sports and exercise research, an increasing emphasis is being placed on obtaining accurate measures to determine the outcomes of various training protocols. Computer modeling, simulation, and virtual reality can be used to evaluate a training protocol that is designed to enhance athletic performance. For example, an athlete can practice specific movements in virtual reality to get a cognitive edge. Such advanced biomechanical methodologies can optimize performance and further improve the design of training programs. In the future, successful training in sports and exercise will rely on both computer technology and various biomechanical measurements of movement.

Virtual Reality Sites: www.cog.brown.edu/Research/ven_lab/

www.mvrc.pitt.edu/index.html

http://biomech.unomaha.edu

Exhibit 9.13: The virtual reality system at the Nebraska Biomechanics Core Facility at the University of Nebraska at Omaha.

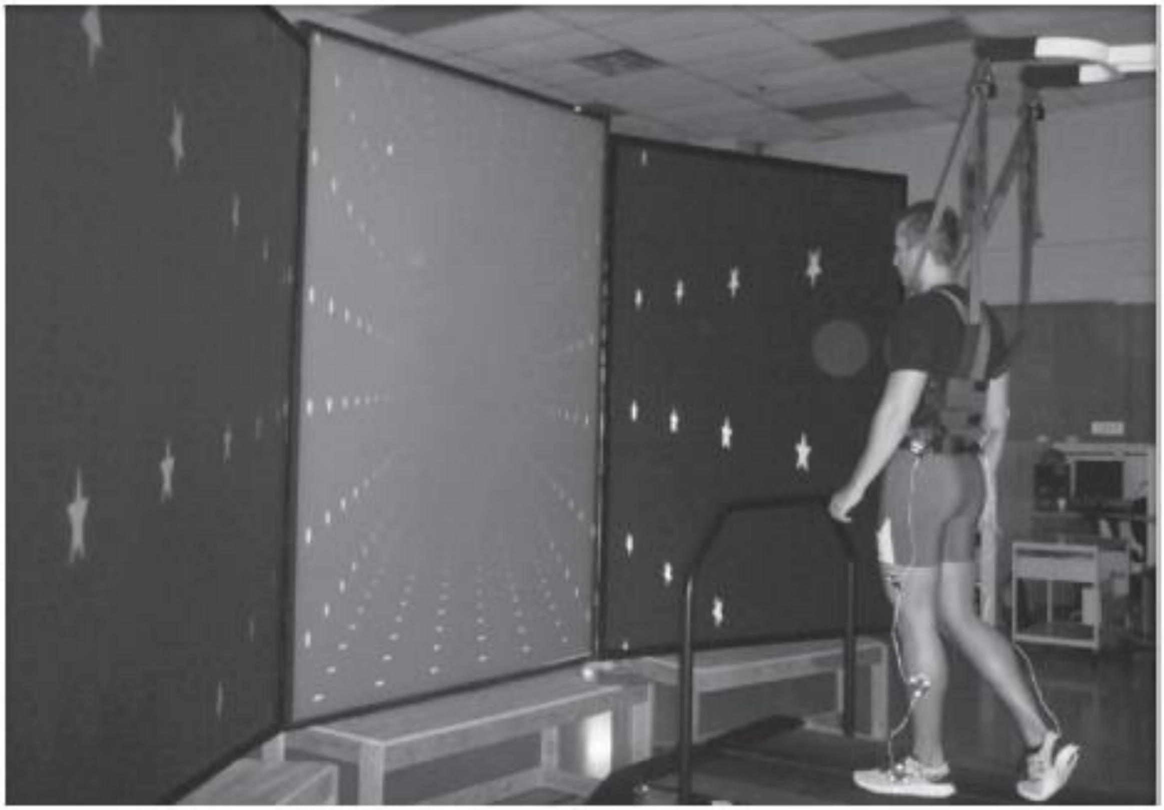

Exhibit 9.14: The wireless Gait-O-Gram® device was developed in the Nebraska Biomechanics Core Facility to study human gait variability.

In clinical settings, biomechanical approaches and methods will commonly be used by physicians, physical therapists, and other specialists. The goals will be to examine pathological human movement and develop more effective treatments for patients to regain their quality of life by using motion analysis and gait evaluations that can be conducted away from the laboratory with inexpensive wireless technology. This technology will also be incorporated into standard clinical examinations in hospitals to increase the precision of the clinical diagnoses.

In occupational science, biomechanically designed environments will be the norm. Currently, the focus is on the engineering of the workplace; however, it is slowly being realized that the interface between the human and the machine is equally important. Thus, biomechanists are needed to work with engineers to design more biologically sound workplace layouts that are safe and will improve productivity.

As the scientific and clinical professions using biomechanical analysis of human movement expand further, the development of new training protocols for athletes and an exploration of new treatments and rehabilitation procedures for patients will follow. The advanced biomechanical technology will become essential to human movement studies in the future.

Summary

Biomechanics is a discipline that uses a wide variety of instruments, techniques, and technologies to study movement. Biomechanists work in a number of areas including developmental biomechanics, biomechanics of exercise and sport, rehabilitative biomechanics, occupational biomechanics, and forensic biomechanics. Because of this diversity, a broad range of knowledge is required. Therefore, many students of biomechanics pursue advanced expertise in master's and doctoral programs. As a result of the variety of applications related to biomechanics, employment opportunities are extremely varied. These opportunities include positions in academia as well as industry and government.

Study Questions

Visit the IES website to study, take notes, and try out the lab for this chapter

1. Explain the focus of developmental biomechanics.

2. The safety and mechanical efficiency of tools would most likely be evaluated by which type of biomechanist?

3. List and describe some optical recording devices.

4. Define biomechanics.

5. Is biomechanics a discipline? Explain.

6. Why do we need to study movement using an interdisciplinary approach?

7. What is the difference between biomechanics and kinesiology?

8. Define kinetics, kinematics, dynamics, and statics.

9. Identify the major areas of research in biomechanics.

10. Give five examples of biomechanical applications.

11. What is a force platform?

12. Name five journals where biomechanists publish their research.

Learning Activities

1. Go to either the International Society of Biomechanics in Sport website (www.isbs.org) or the Canadian Society of Biomechanics website (www. csb-scb.com). Write a brief description of the website's contents.

2. Find two different professional journals that publish articles related to biomechanics. Retrieve one article from each. In your own words, write an abstract for each article.

3. Explore (using the Internet and/or written sources) the job market for biomechanics, and write a brief report on one potential career opportunity.

Suggested Readings

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