B

Behavioral Neuroscience

SUMMARY

Behavioral neuroscience is the study of the role of the nervous system in human and animal behavior. In approaching behavior from a biological framework, behavioral neuroscience considers not only the roles of the physical structures of the brain and other elements of the nervous system in both normal and abnormal behaviors but also the evolution and development of these roles over time.

Behavioral neuroscience is one of several fields in which biology and psychology intersect. It is distinguished from neuropsychology primarily in that while both are experimental fields of psychology, behavioral neuroscience mostly involves experiments using animals, often those whose biology has some correlation to that of humans, while neuropsychology deals more with human subjects, typically with a narrower focus on the structures and functions of the brain and nervous system. Other related fields include evolutionary psychology, affective neuroscience, social neuroscience, behavioral genetics, and neurobiology.

BRIEF HISTORY

While biological models of behavior are not a modern innovation as such, behavioral neuroscience properly speaking is grounded in both a modern understanding of biology—including evolution, the inheritance of genes, and the functions of hormones and neurotransmitters, just for starters—and the science of psychology. Though philosophers and scientists have discussed the mind since ancient times, psychology as an experimental discipline is a product of the nineteenth century, growing out of the Enlightenment's interests in education and in finding humane treatments for mental illness, both of which were served by seeking a way to better understand the workings of the human mind. In a sense, modern biology and modern psychology developed alongside each other: the basic foundations of each were discovered or formulated concurrently, and in the mid-nineteenth century they were brought together in the famous case of Phineas Gage.

A railroad construction foreman, Gage survived an accident in which an iron rod was driven through his head, destroying most of the left frontal lobe of his brain. It left him blind in the affected eye, but less predictably, it changed his personality for the remainder of his life. Reports of the changes in his personality vary, with those dating from after his death being notably more dramatic than the firsthand accounts written during his life, but they concur in the broad strokes—namely, that Gage's behavior after the accident reflected an absence of social inhibition and an increased degree of impulsivity. Popular culture often depicts Gage as becoming violent, depraved, even psychopathic after his accident; few now believe the change to have been this extreme. Reports from later in his life suggest that he was able to eventually relearn and adapt to social and interpersonal mores.

As significant as any change was the simple fact of Gage's survival, as well as the fact that his mental faculties remained intact with so much brain tissue destroyed. In a sense, the details and degree of Gage's personality change are not as important as the excuse he provided for the scientific community to newly address the "mind-body problem" that had concerned the Western intellectual community for centuries. In modern terms, the mind-body problem is the problem of explaining the relationship between the experiences of the nonphysical mind and those of the physical body within which it resides.

AREAS OF RESEARCH

Since Gage's time, biologists have learned more and more about the brain and related structures, and psychologists have conducted countless experiments relating to the mind and behavior. Research in behavioral neuroscience is conducted by observing the behavior of animals in experimental conditions in which some aspect of the animal's nervous system is measured or altered through various means. (Numerous such means exist, including surgical modifications, psychopharmaceuticals, electrical or magnetic stimulation, and genetic engineering.) One of the classic methods is lesion research, which studies animal subjects that have suffered damage to a particular region of the brain. The infliction of surgical lesions, in which brain or other neural tissue is destroyed through surgical removal, has long been a common research method, while the use of neurotoxins to inflict chemical lesions is a more recent development. An even more recent innovation is the use of special anaesthetics and other methods to induce "temporary lesions" by temporarily disabling neural tissue instead of destroying it entirely.

The study of lesions and their effect on behavior helps inform scientific understanding of which structures in the brain contribute to which of its functions. While early models were based on simple one-to-one correlation, demonstrated by literal maps of the brain that showed where various emotions and mental abilities were believed to be generated or exercised, behavioral neuroscience and other disciplines that study the brain have since shown that its workings are far more complicated than that.

Areas of research in behavioral neuroscience focus on broad categories of behavior that humans have in common with animals, namely needs-motivated behaviors, the senses, movement, memory, learning, sleep, emotion, and the relationships among these areas. Behavioral neuroscientists working with certain species—especially cetaceans, cephalopods, and corvids—may also study consciousness, language, or decisionmaking, but these are more controversial areas of inquiry.

Science has always been informed by philosophy. Only in the modern era have science and philosophy truly been separate disciplines, modern science having descended from what Aristotle called "natural philosophy." That said, although both the philosophy of science and the philosophy of biology are esteemed subfields, the philosophy of neuroscience is more newly developed. Until the 1980s, philosophers in the main proceeded without having integrated much specific understanding of neuroscience into their field—and, by extension, were not equipped to comment or contribute specifically to neuroscience.

This changed with Patricia Churchland's *Neurophilosophy* (1986), which was aimed specifically at bridging the gap. Although Churchland included her own views on the philosophy of neuroscience, she also took the time to include a primer on philosophy for neuroscientists and a primer on neuroscience for philosophers. The interdisciplinary relationship between the fields has continued to develop since, and in the twenty-first century, neuroethics became a prominent field, examining the ethical choices and ramifications of neuroscience. In recent years, neuroethicists have raised critical questions about human cognitive enhancements, the ethics of treating neurological impairments, and animal experimentation in behavioral neuroscience.

—Bill Kte'pi, MA

Bibliography

Bickle, John, ed. *The Oxford Handbook of Philosophy and Neuroscience.* New York: Oxford UP, 2009. Print.

Carlson, Neil R. *Foundations of Behavioral Neuroscience.* 9th ed. Boston: Pearson, 2014. Print.

Churchland, Patricia Smith. *Neurophilosophy: Toward a Unified Science of the Mind-Brain.* Cambridge: MIT P, 1986. Print.

Churchland, Patricia S. *Touching a Nerve: The Self as Brain.* New York: Norton, 2013. Print.

Kean, Sam. *The Tale of the Dueling Neurosurgeons: The History of the Human Brain as Revealed by True Stories of Trauma, Madness, and Recovery.* New York: Little, 2014. Print.

Mele, Alfred R. *Free: Why Science Hasn't Disproved Free Will.* New York: Oxford UP, 2014. Print.

Ramachandran, V. S. *The Tell-Tale Brain: A Neuroscientist's Quest for What Makes Us Human.* New York: Norton, 2011. Print.

Binary Pattern

SUMMARY

The binary number system is the more common name for the base-2 numeral system. Unlike the base-10, or decimal system, which uses digits 0-9 to represent numeric values, the binary number system uses only two symbols, traditionally 0 and 1. Thus the binary representations of base-10 “1, 2, 3” are “1, 10, 11.” The binary system is used in computers and other electronics because of its ease of representation with two-state devices such as electrical switches. Throughout history, binary systems have had many uses, including decisionmaking (coin-flipping returns one of two values), divination (the I Ching uses yin/yang system), and encryption (Morse code uses short and long tones), in addition to mathematical applications. Boolean algebra, which became integral to the design of circuitry and computers, was developed by George Boole in 1854 and performs operations with variables assigned the values true or false.

Binary numbers may be manipulated either by conventional arithmetic methods or by using Boolean logical operators in what is usually called a bitwise operation. Bitwise operations are performed by the processor on the individual binary numerals, or bits, of a computer system and are faster and more efficient than arithmetic methods. When computers perform binary operations that result in a 32-bit integer, these operations can be used to form images called binary patterns.

APPLICATION

Despite their underlying simplicity, images formed by binary patterns may appear quite complex. The 32-bit value is key because 32 bits are used in RGBA (Red Green Blue Alpha) color space, in which 8 bits are devoted to the amount of red, green, and blue in an image, with a further 8 bits in the alpha channel reserved for the image’s degree of transparency. Images displayed on computers, television screens, and other LCD screens are made up of pixels, each of which is the smallest physical point on the screen. Pixels are not a standard size, however—in comparing two different same-size screens, the one with the highest resolution has the smallest pixels, and thus a greater number of adjustable points.) These pixels are like incredibly tiny dabs of paint adding up to make a coherent image. In a 32-bit RGBA color space, each pixel is associated with 32 bits of information determining its color and transparency.

Binary patterns can form images that take up much less space in memory than if each pixel were encoded individually, by instead storing the formula or series of binary operations used to form the image. Many computer operating systems include basic patterns and tiles that take up a fraction of the space of an image like a photograph, which can’t be reconstructed by binary operations. They may be simple repeated shapes, or intricate patterns reminiscent of murals and mandalas.

—Bill Kte’pi, MA

Bibliography

Kolo, Brian. *Binary and Multiclass Classification.* New York: Weatherford, 2010.

Kjaerulff, Uffe, and Anders Madsen. *Bayesian Networks and Influence Diagrams.* New York: Springer, 2014.

Larcher, Gerhard, and Friedrich Pilichshammer, eds. *Applied Algebra and Number Theory.* New York: Cambridge UP, 2015.

Marchand-Maillet, S. *Binary Digital Image Processing.* Waltham, MA: Academic P, 1999.

Nicholas, Patrick. *Scala for Machine Learning.* New York: Packt, 2014.

Reba, Marilyn, and Douglas R. Shier. *Puzzles, Paradoxes, and Problem Solving.* New York: Chapman, 2014.

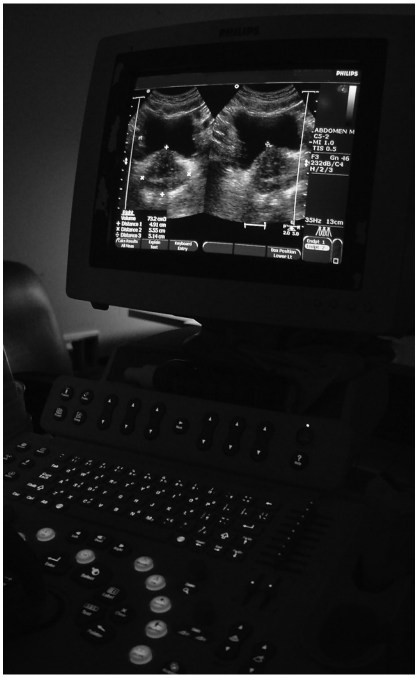
Stakhov, Alexey, and Scott Anthony Olsen. *The Mathematics of Harmony.* Hackensack: World Scientific, 2009.

Yager, Ronald, and Ali Abbasov, eds. *Soft Computing.* New York: Springer, 2014.

Biomechanical Engineering

SUMMARY

Biomechanical engineering is a branch of science that applies mechanical engineering principles such as physics and mathematics to biology and medicine. It can be described as the connection between structure and function in living things. Researchers in this field investigate the mechanics and mechanobiology of cells and tissues, tissue engineering, and the physiological systems they comprise. The work also examines the pathogenesis and treatment of diseases using cells and cultures, tissue mechanics, imaging, microscale biosensor fabrication, biofluidics, human motion capture, and computational methods. Real-world applications include the design and evaluation of medical implants, instrumentation, devices, products, and procedures. Biomechanical engineering is a multidisciplinary science, often fostering collaborations and interactions with medical research, surgery, radiology, physics, computer modeling, and other areas of engineering.



Ultrasound representation of Urinary bladder (black butterfly-like shape) with a hyperplastic prostate. An example of engineering science and medical science working together. By Etan J. Tal (Own work)

DEFINITION AND BASIC PRINCIPLES

Biomechanical engineering applies mechanical engineering principles to biology and medicine. Elements from biology, physiology, chemistry, physics, anatomy, and mathematics are used to describe the impact of physical forces on living organisms. The forces studied can originate from the outside environment or generate within a body or single structure. Forces on a body or structure can influence how it grows, develops, or moves. Better understanding of how a biological organism copes with forces and stresses can lead to improved treatment, advanced diagnosis, and prevention of disease. This integration of multidisciplinary philosophies has lead to significant advances in clinical medicine and device design. Improved understanding guides the creation of artificial organs, joints, implants, and tissues. Biomechanical engineering also has a tremendous influence on the retail industry, as the results of laboratory research guide product design toward more comfortable and efficient merchandise.

BACKGROUND AND HISTORY

The history of biomechanical engineering, as a distinct and defined field of study, is relatively short. However, applying the principles of physics and engineering to biological systems has been developed over centuries. Many overlaps and parallels to complementary areas of biomedical engineering and biomechanics exist, and the terms are often used interchangeably with biomechanical engineering. The mechanical analysis of living organisms was not internationally accepted and recognized until the definition provided by Austrian mathematician Herbert Hatze in 1974: "Biomechanics is the study of the structure and function of biological systems by means of the methods of mechanics."

Greek philosopher Aristotle introduced the term "mechanics" and discussed the movement of living beings around 322 BCE in the first book about biomechanics, *On the Motion of Animals*. Leonardo da Vinci proposed that the human body is subject to the law of mechanics in the 1500s. Italian physicist and mathematician Giovanni Alfonso Borelli, a student of Galileo's, is considered the "father of biomechanics" and developed mathematical models to describe anatomy and human movement mechanically. In the 1890s German zoologist Wilhelm Roux and German surgeon Julius Wolff determined the effects of loading and stress on stem cells in the development of bone architecture and healing. British physiologist Archibald V. Hill and German physiologist Otto Fritz Meyerhof shared the 1922 Nobel Prize for Physiology or Medicine. The prize was divided between them: Hill won "for his discovery relating to the production of heat in the muscle"; Meyerhof won "for his discovery of the fixed relationship between the consumption of oxygen and the metabolism of lactic acid in the muscle."

The first joint replacement was performed on a hip in 1960 and a knee in 1968. The development of imaging, modeling, and computer simulation in the latter half of the twentieth century provided insight into the smallest structures of the body. The relationships between these structures, functions, and the impact of internal and external forces accelerated new research opportunities into diagnostic procedures and effective solutions to disease. In the 1990s, biomechanical engineering programs began to emerge in academic and research institutions around the world, and the field continued to grow in recognition into the twenty-first century.

HOW IT WORKS

Biomechanical engineering science is extremely diverse. However, the basic principle of studying the relationship between biological structures and forces, as well as the important associated reactions of biological structures to technological and environmental materials, exists throughout all disciplines. The biological structures described include all life forms and may include an entire body or organism or even the microstructures of specific tissues or systems. Characterization and quantification of the response of these structures to forces can provide insight into disease process, resulting in better treatments and diagnoses. Research in this field extends beyond the laboratory and can involve observations of mechanics in nature, such as the aerodynamics of bird flight, hydrodynamics of fish, or strength of plant root systems, and how these findings can be modified and applied to human performance and interaction with external forces.

As in biomechanics, biomechanical engineering has basic principles. Equilibrium, as defined by British physicist Sir Isaac Newton, results when the sum of all forces is zero and no change occurs and energy cannot be created or destroyed, only converted from one form to another.

The seven basic principles of biomechanics can be applied or modified to describe the reaction of forces to any living organism.

The lower the center of mass, the larger the base of support; the closer the center of mass to the base of support, and the greater the mass, the more stability increases.

The production of maximum force requires the use of all possible joint movements that contribute to the task's objective.

The production of maximum velocity requires the use of joints in order—from largest to smallest.

The greater the applied impulse, the greater increase in velocity.

Movement usually occurs in the direction opposite that of the applied force.

Angular motion is produced by the application of force acting at some distance from an axis, that is, by torque.

Angular momentum is constant when a body or object is free in the air.

The forces studied can be combinations of internal, external, static, or dynamic, and all are important in the analysis of complex biochemical and biophysical processes. Even the mechanics of a single cell, including growth, cell division, active motion, and contractile mechanisms, can provide insight into mechanisms of stress, damage of structures, and disease processes at the microscopic level. Imaging and computer simulation allow precise measurements and observations to be made of the forces impacting the smallest cells.

APPLICATIONS AND PRODUCTS

Biomechanical engineering advances in modeling and simulation have tremendous potential research and application uses across many health care disciplines. Modeling has resulted in the development of designs for implantable devices to assist with organs or areas of the body that are malfunctioning. The biomechanical relationships between organs and supporting structures allow for improved device design and can assist with planning of surgical and treatment interventions. The materials used for medical and surgical procedures in humans and animals are being evaluated and some redesigned, as biomechanical science is showing that different materials, procedures, and techniques may be better for reducing complications and improving long-term patient health. Evaluating the physical relationship between the cells and structures of the body and foreign implements and interventions can quantify the stresses and forces on the system, which provides more accurate prediction of patient outcomes.

Biomechanical engineering professionals apply their knowledge to develop implantable medical devices that can diagnose, treat, or monitor disease and health conditions and improve the daily living of patients. Devices that are used within the human body are highly regulated by the U.S. Food and Drug Administration (FDA) and other agencies internationally. Pacemakers and defibrillators, also called cardiac resynchronization therapy (CRT) devices, can constantly evaluate a patient's heart and respond to changes in heart rate with electrical stimulation. These devices greatly improve therapeutic outcomes in patients afflicted with congestive heart failure. Patients with arrhythmias experience greater advantages with implantable devices than with pharmaceutical options. Cochlear implants have been designed to be attached to a patient's auditory nerve and can detect sound waves and process them in order to be interpreted by the brain as sound for deaf or hard-of-hearing patients. Patients who have had cataract surgery used to have to wear thick corrective lenses to restore any standard of vision, but with the development of intraocular lenses that can be implanted into the eye, their vision can be restored, often to a better degree than before the cataract developed.

Artificial replacement joints comprise a large portion of medical-implant technology. Patients receive joint replacement when their existing joints no longer function properly or cause significant pain because of arthritis or degeneration. Hundreds of thousands of hip replacements are performed in the United States each year, a number that has grown significantly as the baby boomer portion of the population ages. Artificial joints are normally fastened to the existing bone by cement, but advances in biomechanical engineering have lead to a new process called "bone ingrowth," in which the natural bone grows into the porous surface of the replacement joint. Biomechanical engineering contributes considerable knowledge to the design of the artificial joints, the materials from which they are made, the surgical procedure used, fixation techniques, failure mechanisms, and prediction of the lifetime of the replacement joints.

The development of computer-aided (CAD) design has allowed biomechanical engineers to create complex models of organs and systems that can provide advanced analysis and instant feedback. This information provides insight into the development of designs for artificial organs that align with or improve on the mechanical properties of biological organs.

Biomechanical engineering can provide predictive values to medical professionals, which can help them develop a profile that better forecasts patient outcomes and complications. An example of this is using finite element analysis in the evaluation of aortic-wall stress, which can remove some of the unpredictability of expansion and rupture of an abdominal aortic aneurysm. Biomechanical computational methodology and advances in imaging and processing technology have provided increased predictability for life-threatening events.

Nonmedical applications of biomechanical engineering also exist in any facet of industry that impacts human life. Corporations employ individuals or teams to use engineering principles to translate the scientifically proven principles into commercially viable products or new technological platforms. Biomechanical engineers also design and build experimental testing devices to evaluate a product's performance and safety before it reaches the marketplace, or they suggest more economically efficient design options. Biomechanical engineers also use ergonomic principles to develop new ideas and create new products, such as car seats, backpacks, or even specialized equipment and clothing for elite athletes, military personnel, or astronauts.

SOCIAL CONTEXT AND FUTURE PROSPECTS

The diversity of studying the relationship between living structure and function has opened up vast opportunities in science, health care, and industry. In addition to conventional implant and replacement devices, the demand is growing for implantable tissues for cosmetic surgery, such as breast and tissue implants, as well as implantable devices to aid in weight loss, such as gastric banding.

Reports of biomechanical engineering triumphs and discoveries often appear in the mainstream media, making the general public more aware of the scientific work being done and how it impacts daily life. Sports fans learn about the equipment, training, and rehabilitation techniques designed by biomechanical engineers that allow their favorite athletes to break performance records and return to work sooner after being injured or having surgery. The public is accessing more information about their own health options than ever before, and they are becoming knowledgeable about the range of treatments available to them and the pros and cons of each.

Biomechanical engineering and biotechnology is an area that is experiencing accelerated growth, and billions of dollars are being funneled into research and development annually. This growth is expected to continue.

—April D. Ingram, BSc

Bibliography

"Biomechanics." *Engineering in Medicine and Biology Society*, IEEE, 2018, www.embs.org/about-biomedical-engineering/our-areas-of-research/biomechanics/. Accessed 19 Mar. 2018.

Ethier, C. Ross, and Craig A. Simmons. *Introductory Biomechanics: From Cells to Organisms.* Cambridge, England: Cambridge University Press, 2007. Provides an introduction to biomechanics and also discusses clinical specialties, such as cardiovascular, musculoskeletal, and ophthalmology.

Hall, Susan J. *Basic Biomechanics.* 5th ed. New York: McGraw-Hill, 2006. A good introduction to biomechanics, regardless of one's math skills.

Hamill, Joseph, and Kathleen M. Knutzen. *Biomechanical Basis of Human Movement.* 3d ed. Philadelphia: Lippincott, 2009. Integrates anatomy, physiology, calculus, and physics and provides the fundamental concepts of biomechanics.

Hay, James G., and J. Gavin Reid. *Anatomy, Mechanics, and Human Motion.* 2d ed. Englewood Cliffs, N.J.: Prentice Hall, 1988. A good resource for upper high school students, this text covers basic kinesiology.

Hayenga, Heather N., and Helim Aranda-Espinoza. *Biomaterials Mechanics.* CRC Press, 2017.

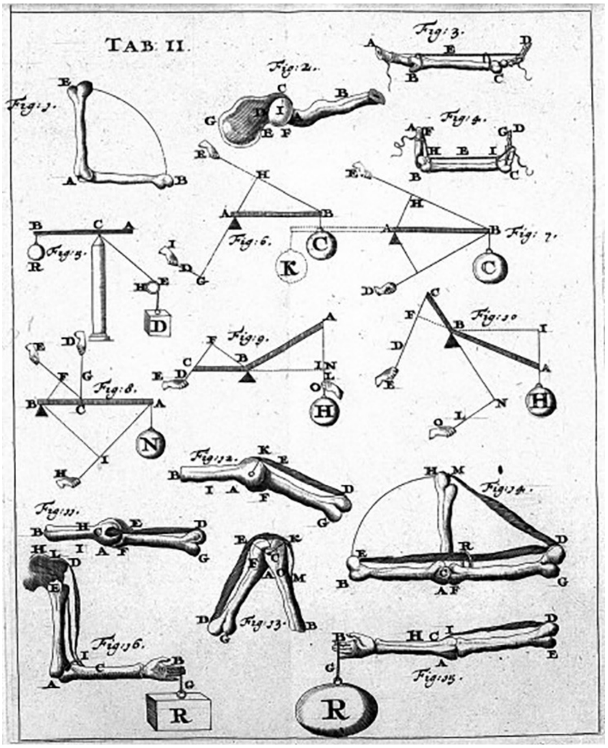
Peterson, Donald R., and Joseph D. Bronzino, eds. *Biomechanics: Principles and Applications.* 2d ed. Boca Raton, Fla.: CRC Press, 2008. A collection of twenty articles on various aspects of research in biomechanics.

Prendergast, Patrick, ed. *Biomechanical Engineering: From Biosystems to Implant Technology.* London: Elsevier, 2007. One of the first comprehensive books for biomechanical engineers, written with the student in mind.

Biomechanics

SUMMARY

Biomechanics is the study of the application of mechanical forces to a living organism. It investigates the effects of the relationship between the body and forces applied either from outside or within. In humans, biomechanists study the movements made by the body, how they are performed, and whether the forces produced by the muscles are optimal for the intended result or purpose. Biomechanics integrates the study of anatomy and physiology with physics, mathematics, and engineering principles. It



Page of one of the first works of biomechanics (De Motu Animalium of Giovanni Alfonso Borelli). By Giovanni Alfonso Borelli (De Motu Animalium book)

may be considered a subdiscipline of kinesiology as well as a scientific branch of sports medicine.

DEFINITION AND BASIC PRINCIPLES

Biomechanics is a science that closely examines the forces acting on a living system, such as a body, and the effects that are produced by these forces. External forces can be quantified using sophisticated measuring tools and devices. Internal forces can be measured using implanted devices or from model calculations. Forces on a body can result in movement or biological changes to the anatomical tissue. Biomechanical research quantifies the movement of different body parts and the factors that may influence the movement, such as equipment, body alignment, or weight distribution. Research also studies the biological effects of the forces that may affect growth and development or lead to injury. Two distinct branches of mechanics are statics and dynamics. Statics studies systems that are in a constant state of motion or constant state of rest, and dynamics studies systems that are in motion, subject to acceleration or deceleration. A moving body may be described using kinematics or kinetics. Kinematics studies and describes the motion of a body with respect to a specific pattern and speed, which translate into coordination of a display. Kinetics studies the forces associated with a motion, those causing it and resulting from it. Biomechanics combines kinetics and kinematics as they apply to the theory of mechanics and physiology to study the structure and function of living organisms.

BACKGROUND AND HISTORY

Biomechanics has a long history even though the actual term and field of study concerned with mechanical analysis of living organisms was not internationally accepted and recognized until the early 1970s. Definitions provided by early biomechanics specialists James G. Hay in 1971 and Herbert Hatze in 1974 are still accepted. Hatze stated, “Biomechanics is the science which studies structures and functions of biological systems using the knowledge and methods of mechanics.”

Highlights throughout history have provided insight into the development of this scientific discipline. The ancient Greek philosopher Aristotle was the first to introduce the term “mechanics,” writing about the movement of living beings around 322 BCE. He developed a theory of running techniques and suggested that people could run faster by swinging their arms. In the 1500s, Leonardo da Vinci proposed that the human body is subject to the law of mechanics, and he contributed significantly to the development of anatomy as a modern science. Italian scientist Giovanni Alfonso Borelli, a student of Galileo, is often considered the father of biomechanics. In the mid-1600s, he developed mathematical models to describe anatomy and human movement mechanically. In the late 1600s, English physician and mathematician Sir Isaac Newton formulated mechanical principles and Newtonian laws of motion (inertia, acceleration, and reaction) that became the foundation of biomechanics.

British physiologist A. V. Hill, the 1923 winner of the Nobel Prize in Physiology or Medicine, conducted research to formulate mechanical and structural theories for muscle action. In the 1930s, American anatomy professor Herbert Elftman was able to quantify the internal forces in muscles and joints and developed the force plate to quantify ground reaction. A significant breakthrough in the understanding of muscle action was made by British physiologist Andrew F. Huxley in 1953, when he described his filament theory to explain muscle shortening. Russian physiologist Nicolas Bernstein published a paper in 1967 describing theories for motor coordination and control following his work studying locomotion patterns of children and adults in the Soviet Union.

HOW IT WORKS

The study of human movement is multifaceted, and biomechanics applies mechanical principles to the study of the structure and function of living things. Biomechanics is considered a relatively new field of applied science, and the research being done is of considerable interest to many other disciplines, including zoology, orthopedics, dentistry, physical education, forensics, cardiology, and a host of other medical specialties. Biomechanical analysis for each particular application is very specific; however, the basic principles are the same.

Newton's Laws of Motion. The development of scientific models reduces all things to their basic level to provide an understanding of how things work. This also allows scientists to predict how things will behave in response to forces and stimuli and ultimately to influence this behavior.

Newton's laws describe the conservation of energy and the state of equilibrium. Equilibrium results when the sum of forces is zero and no change occurs, and conservation of energy explains that energy cannot be created or destroyed, only converted from one form to another. Motion occurs in two ways, linear motion in a particular direction or rotational movement around an axis. Biomechanics explores and quantifies the movement and production of force used or required to produce a desired objective.

Seven Principles. Seven basic principles of biomechanics serve as the building blocks for analysis. These can be applied or modified to describe the reaction of forces to any living organism.

The lower the center of mass, the larger the base of support; the closer the center of mass to the base of support and the greater the mass, the more stability increases.

The production of maximum force requires the use of all possible joint movements that contribute to the task's objective.

The production of maximum velocity requires the use of joints in order, from largest to smallest.

The greater the applied impulse, the greater increase in velocity.

Movement usually occurs in the direction opposite that of the applied force.

Angular motion is produced by the application of force acting at some distance from an axis, that is, by torque.

Angular momentum is constant when an athlete or object is free in the air.

Static and dynamic forces play key roles in the complex biochemical and biophysical processes that underlie cell function. The mechanical behavior of individual cells is of interest for many different biologic processes. Single-cell mechanics, including growth, cell division, active motion, and contractile mechanisms, can be quite dynamic and provide insight into mechanisms of stress and damage of structures. Cell mechanics can be involved in processes that lie at the root of many diseases and may provide opportunities as focal points for therapeutic interventions.

APPLICATIONS AND PRODUCTS

Biomechanics studies and quantifies the movement of all living things, from the cellular level to body systems and entire bodies, human and animal. There are many scientific and health disciplines, as well as industries that have applications developed from this knowledge. Research is ongoing in many areas to effectively develop treatment options for clinicians and better products and applications for industry.

Dentistry. Biomechanical principles are relevant in orthodontic and dental science to provide solutions to restore dental health, resolve jaw pain, and manage cosmetic and orthodontic issues. The design of dental implants must incorporate an analysis of load bearing and stress transfer while maintaining the integrity of surrounding tissue and comfortable function for the patient. This work has lead to the development of new materials in dental practices such as reinforced composites rather than metal frameworks.

Forensics. The field of forensic biomechanical analysis has been used to determine mechanisms of injury after traumatic events such as explosions in military situations. This understanding of how parts of the body behave in these events can be used to develop mitigation strategies that will reduce injuries. Accident and injury reconstruction using biomechanics is an emerging field with industrial and legal applications.

Biomechanical Modeling. Biomechanical modeling is a tremendous research field, and it has potential uses across many health care applications. Modeling has resulted in recommendations for prosthetic design and modifications of existing devices. Deformable breast models have demonstrated capabilities for breast cancer diagnosis and treatment. Tremendous growth is occurring in many medical fields that are exploring the biomechanical relationships between organs and supporting structures. These models can assist with planning surgical and treatment interventions and reconstruction and determining optimal loading and boundary constraints during clinical procedures.

Materials. Materials used for medical and surgical procedures in humans and animals are being evaluated and some are being changed as biomechanical science is demonstrating that different materials, procedures, and techniques may be better for reducing complications and improving long-term patient health. Evaluation of the physical relationship between the body and foreign implements can quantify the stresses and forces on the body, allowing for more accurate prediction of patient outcomes and determination of which treatments should be redesigned.

Predictability. Medical professionals are particularly interested in the predictive value that biomechanical profiling can provide for their patients. An example is the unpredictability of expansion and rupture of an abdominal aortic aneurysm. Major progress has been made in determining aortic wall stress using finite element analysis. Improvements in biomechanical computational methodology and advances in imaging and processing technology have provided increased predictive ability for this life-threatening event.

As the need for accurate and efficient evaluation grows, so does the research and development of effective biomechanical tools. Capturing real-time, real-world data, such as with gait analysis and range of motion features, provides immediate opportunities for applications. This real-time data can quantify an injury and over time provide information about the extent that the injury has improved. High-tech devices can translate real-world situations and two-dimensional images into a three-dimensional framework for analysis. Devices, imaging, and modeling tools and software are making tremendous strides and becoming the heart of a highly competitive industry aimed at simplifying the process of analysis and making it less invasive.

SOCIAL CONTEXT AND FUTURE PROSPECTS

Biomechanics has gone from a narrow focus on athletic performance to become a broad-based science, driving multibillion dollar industries to satisfy the needs of consumers who have become more knowledgeable about the relationship between science, health, and athletic performance. Funding for biomechanical research is increasingly available from national health promotion and injury prevention programs, governing bodies for sport, and business and industry. National athletic programs want to ensure that their athletes have the most advanced training methods, performance analysis methods, and equipment to maximize their athletes' performance at global competitions.

Much of the existing and developing technology is focused on increasingly automated and digitized systems to monitor and analyze movement and force. The physiological aspect of movement can be examined at a microscopic level, and instrumented athletic implements such as paddles or bicycle cranks allow real-time data to be collected during an event or performance. Force platforms are being reconfigured as starting blocks and diving platforms to measure reaction forces. These techniques for biomechanical performance analysis have led to revolutionary technique changes in many sports programs and rehabilitation methods.

Advances in biomechanical engineering have led to the development of innovations in equipment, playing surfaces, footwear, and clothing, allowing people to reduce injury and perform beyond previous expectations and records.

Computer modeling and virtual simulation training can provide athletes with realistic training opportunities, while their performance is analyzed and measured for improvement and injury prevention.

—April D. Ingram, BSc

Bibliography

Bronzino, Joseph D., and Donald R. Peterson. *Biomechanics: Principles and Practices.* Boca Raton: CRC, 2014. *eBook Collection (EBSCOhost)*. Web. 25 Feb. 2015.

Hamill, Joseph, and Kathleen Knutzen. *Biomechanical Basis of Human Movement.* 4th ed. Philadelphia: Lippincott, 2015. Print.

Hatze, H. “The Meaning of the Term ‘Biomechanics.’” *Journal of Biomechanics* 7.2 (1974): 89–90. Print.

Hay, James G. *The Biomechanics of Sports Techniques.* 4th ed. Englewood Cliffs: Prentice, 1993. Print.

Kerr, Andrew. *Introductory Biomechanics.* London: Elsevier, 2010. Print.

Peterson, Donald, and Joseph Bronzino. *Biomechanics: Principles and Applications.* Boca Raton: CRC, 2008. Print.

Watkins, James. *Introduction to Biomechanics of Sport and Exercise.* London: Elsevier, 2007. Print.

Biomimetics

SUMMARY

Biomimetics is a branch of science that uses observations in nature to inspire the development of new products or technologies in fields such as medicine, engineering, and architecture. By observing aspects of plant and animal life, researchers can find new ways to perform tasks or develop designs that can be adapted for man-made products. Mimicking biological life through biomimetics has allowed for many scientific innovations.

BACKGROUND

The idea of copying nature is not new. The Greek myth of Icarus, who constructed wings from feathers and wax in an attempt to fly, illustrates that man has long sought to imitate wonders found in the natural world. Centuries after the Greeks told the story of Icarus, Italian Renaissance thinker, artist, and inventor Leonardo da Vinci used birds as models for his intricate drawings of human flight devices. In the early years of the twentieth century, the Wright brothers studied the design of bird wings and incorporated aspects of them into the design of the first airplane. For many years, these attempts to mimic aspects of nature were largely accomplished by individuals and were not a specific discipline of study.

Velcro tape mimics biological examples of multiple hooked structures such as burs. By Ryj (Own work)