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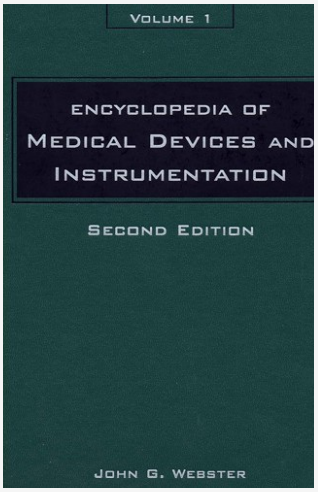
Biomechanics of Exercise Fitness

Scientific Bases for Fitness and Exercise Equipment



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BIOMECHANICS OF EXERCISE FITNESS

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INTRODUCTION

Normal human development spans a lifetime from infancy to old age. Modern civilization is confronted with the lengthening of that time and its effect on the individual and society. Housing improvements, employment alterations, labor saving devices, and modern medicine are but a few of the factors protecting humanity from those instances which previously shortened life. While many of the difficult, threatening experiences have been eliminated or reduced in severity, problems remain to be solved. Concerns for the quality of life as people become older include maintaining self-sufficiency. Many solutions conflict with beliefs generally termed "current wisdom" in areas, such as training, dieting, exercising, and aging. While society ages, the challenge for each individual is to strive to retain the lowest "biological" age while their "chronological" birthdays increase. The dilemma concerns the best way to accomplish this task.

The main purpose of this article is to focus on the biomechanical principles of movement, the scientific bases of training and fitness, and the optimization of human performance at any age. These are not just nonsense concepts added to the quantities of known theories, but are objectively quantifiable procedures that encompass our understandings and can produce precise conclusions. Mathematical principles and gravitational formulations provide the cornerstones for optimizing human performance. Biological, anatomical, physiological, and medical discoveries are always under investigation, challenge, and improvement and these findings will be incorporated into many of the current theories. Figure 1 illustrates just part of the anatomy and its complicated structure. The struggle will continue among scientists to establish new principles for revolutionizing the world of gerontology, diet, physical fitness and training, and amplifying those factors necessary for extending life not only in length, but also in quality. Scientists with expertise in many different areas will be addressing the problems associated with aging from their specialized perspective.

In order to address the optimization of human movement and performance, the underlying philosophical premise metaphorically compares life with sport. The goal is that everyone should be a gold medalist in their own body regardless of age. Most people, however, do not achieve their Gold Medal because their goals, potential, and/or timing are uncoordinated or nonexistent. For example, an individual may envision themselves as a tennis champion, yet lack the requisite physical and physiological traits of the greatest players. Given this situation, can a person's potential be maximized? Achieving one's maximum potential necessitates tools applicable to everyone for improving their performance, whether in tennis, fitness, overcoming physical handicaps, or fighting disease. Useful tools must be based, however, on correct, substantive scientific principles.

SCIENTIFIC PRINCIPLES FOR QUANTIFYING MOTION

Human movement has fascinated humans for centuries including some of the world's greatest thinkers, such as Leonardo da Vinci, Giovanni Borelli, Wilhelm Braune, and others. Many questions posed by these stellar geniuses have been or can be addressed by the relatively new area of Biomechanics. Biomechanics is the study of the motion of living things, primarily, and it has evolved from a fusion of the classic disciplines of anatomy, physiology, physics, and engineering. Bio refers to the biological portion, incorporating muscles, tendons, nerves, and so on, while mechanics is associated with the engineering concepts based upon the laws described by Sir Isaac Newton. Human bodies consist of a set of levers that are powered by muscles. Quantification of movements, whether human, animal, or inanimate objects, can be treated within biomechanics according to Newtonian equations. It may seem obvious, with the perfect vision of hind sight, that humans and their activities, such as the wielding of tools (e.g., hammer, axe) or implements (e.g., baseball bat, golf club, discus), must obey the constraints of gravitational bodies, just as bridges, buildings, and cars do. For some inexplicable reason, humans and their activities had not been subjected to the appropriate engineering concepts that architects would use when determining the weight of books to be housed in a new library or engineers would apply to designing a bridge to span a wide, yawning abyss. It was not until Newton's

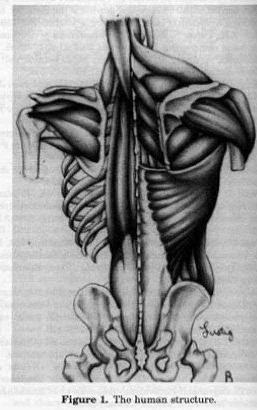

Figure 1. The human structure.

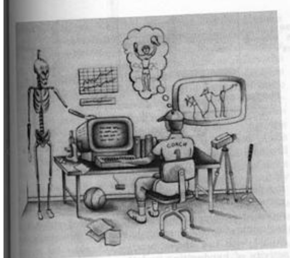

Figure 2. The modern coach and his tools.

apple fell again during the twentieth century that biomechanics was born.

Biomechanics, then, is built on a foundation of knowledge and the application of the basic physical laws of gravitational effects as well as those of anatomy, chemistry, physiology, and other human sciences. Early quantification efforts of human movement organized the body as a system of mechanical links. Activities were recorded on movie film that normally consisted of hundreds of frames for each of the desired movement segment. Since each frame of the activity had to be processed individually, the task was excessively lengthy, tedious, and time intensive. Figure 2 illustrates an abstract of todays sophisticated coaching tools in athletics. The hand calculations of a typical 16 segment biomechanical human required many hours for each frame, necessitating either numerous assistants or an individual investigator's labor-of-love and, frequently, both. Unfortunately, these calculations were susceptible to numerical errors.

The introduction of large, main-frame computers improved reliability and reasonableness of the results, replacing much of the skepticism or distrust associated with the manually computed findings. Computerization accelerated the calculations of a total movement much more rapidly than had been previously possible, but presented new difficulties to overcome. Many of the early biomechanical programs were cumbersome, time intensive main-frame endeavors with little appeal except to the obsessed, devotee of computers, and movement assessment. However, even these obstacles were conquered in the ever expanding computerization era. The computerized hardware/software system provides a means to objectively quantify the dynamic components of movement in humans regardless of the nature of the event. Athletic events, gait analyses, job-related actions as well as motion by inanimate objects, including machine parts, air bags, and auto crash dummies are all reasonable analytic candidates. Objectivity replaces mere observation and supposition.

One of the most important aspects included in the Bio portion of biomechanics is the musculoskeletal system. Voluntary human movement is caused by muscular contractions that move bones connected at joints. The neuromuscular system functions as a hierarchical system with autonomic and basic, life sustaining operations, such as heart rate and digestion, controlled at the lowest, noncognitive levels and with increasing complexities and regulatory operations, such as combing the hair or kicking a ball, controlled by centers that are further up the nervous system. Interaction of the various control centers is regulated through two fundamental techniques each governed like a servosystem.

The first technique equips each level of decision making with subprocessors that accept the commands from higher levels as well as accounting for the inputs from local feedback and environmental information sensors. Thus, a descending pyramid of processors is defined that can accept general directives and execute them in the presence of varying loads, stresses, and other perturbations. This type of input–output control is used for multimodal processes, such as maintaining balance while walking on an uneven terrain, but would be inappropriate for executing deliberate, volitional, complex tasks like the conductor using the baton to coordinate the music of the performing musicians.

The second technique utilized by the brain to control muscular contractions applies to the operation of higher level systems that generate output strategies in relation to behavioral goals. These tasks use information from certain sensory inputs, including joint angle, muscle loading, and muscular extension or flexion that are assessed, transmitted to higher centers for computation, which then executes the set of modified neural transmissions received. Cognitive tasks requiring the type of informational input that influences actions are the ones with which humans are most familiar since job execution requires more thought than breathing or standing upright. A frequently misunderstood concept is that limb movement is possible only through contractions of individual muscle fibers. For most cases of voluntary activity, muscles work in opposing pairs with one set of muscles opening or extending the joint (extensors) while the opposite muscle group closes or flexes the joint. The degree of contraction is proportional to the frequency of signals from the nerve as signaled from the higher centers. Movement control is provided by a programmable mechanism so that when flexors contract, the extensors relax, and vice versa. The motor integration programmed generated in the higher, cognitive levels regulates not only the control of the muscle groups around a joint, but also those necessary actions by other muscles and limbs to redistribute weight, to counteract shifts in the center of gravity.

One of the most important, but frequently misunderstood, concepts of the nervous system is the control and regulation of coordinated movement. When a decision is made to move a body segment, the prime muscles or agonists receive a signal to contract. The electrical burst stimulates the agonist muscular activity causing an acceleration of the segment in the desired direction. At the same time, a smaller signal is transmitted to the opposite muscle group, or antagonist, which causes it to function as a joint stabilizer. With extremely rapid movements, the antagonist is frequently stimulated to slow the limb in time to

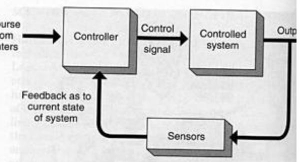

Figure 3. Feedback control mechanism of movement.

protect the joint from injury. It is the strength and duration of the electrical signal to both the agonist and antagonist that govern the desired action. The movement of agonists and antagonists, whether a cognitive process, such as throwing a ball, or an acquired activity, such as postural control, is controlled by the nervous system. Figure 3 illustrates a flowchart for the control system for movement. Many ordinary voluntary human activities resulting from agonist–antagonist muscular contraction are classified by different terms, isotonic, variable resistance, and ballistic. Slower movements, demonstrating smaller, more frequent, electrical signal alterations, are intricately controlled by both agonist and antagonist. These types of motion are tracking movements.

One control mechanism available involves the process of information channeled between the environment and the musculature. Closed-loop control involves the use of feedback whereby differences between actual and desired posture are detected and subsequently corrected, whereas open-loop control utilizes feed forward strategies that involve the generation of a command based on prior experience rather than on feedback. Braitenberg and Onesto (ARBIB) proposed a network for converting space into time by providing that the position of an input would determine the time of the output. This open loop system would trigger a preset signal from the nervous system to the muscle generating a known activity. Kicking a ball, walking, throwing a baseball, swinging a golf club, and hand writing are considered ballistic movements.

When a limb moves, a sophisticated chain of events occurs before, during, and after the movement is completed. The fineness of control depends on the number of muscle fibers innervated by each motor neuron. A motor unit is generally defined as a single motor neuron and the number of muscle fibers it innervates. Fine control is achieved when a single motor neuron innervates just a few fibers. Less fine control, as in many large muscle groups, is attained when individual motor units innervate hundreds or even thousands of fibers. The more neurons there are, the finer the ability to maneuver, as with eye movements or delicate hand manipulations. In contrast to the high innervations ratio of the eye, the biceps of the arm has a very low rate of nerve-to-muscle fiber resulting in correspondingly more coarse movements.

While the amount of nervous innervations is important when anticipating the precision of control, the manner of interaction and timing between muscles, nerves, and desired outcome is probably more important when evaluating performance. Recognizable actions elicit executi patterned, synchronous nervous activity. Frequ repeated movements are usually performed crudely i beginning stages of learning, but become increasingly skilled with use and/or practice. Consider the con activity of handwriting and the execution of one's signature. The evolution from a child's irregular, printing to an adult's recognizable, consistently repea signature is normal. Eventually, the individual's signa begins to appear essentially the same every time a uniquely different from any other person. Not only ca person execute handwritten signatures consistency, bu use chalk to sign the name in large letters on a blackb producing a recognizably similar appearance. The in duality of the signature remains whether using the control of the hand or recruiting the large shoulder and muscles not normally required for the task. Reproducti recognizable movements occurs from preprogrammed trol patterns stored in the brain and recruited as neces Practicing a golf swing until it results in a 300 yard down the middle of the fairway, getting the food-laden from the plate into the mouth, and remembering how to a bike after a 30 year hiatus illustrate learned behavior has become "automatic" with practice and can be reca from the brain's storage for execution.

Volitional tasks require an integration of neurolog physiological, biochemical, and mechanical compone There are many options available when performing a t such as walking, but eventually, each person will devel pattern that will be recognizable as that skill, repeata and with a certain uniqueness associated with that pa cular individual. Although any person's movement coul quantified with biomechanical applications and compa to other performers in a similar group, for example, gold, silver, and bronze medalists in an Olympic ev perhaps it will be the ability to compare one person themselves that will provide the most meaningful as tance in the assault on aging.

There are many areas of daily living in which bio chanical analyses could be useful. Biomechanics could utilized to design a house or chair to suit the body or to bigger, heavier objects with less strain. This science co be useful in selecting the most appropriate athletic ev for children or for improving an adult's performance. W increasing international interest in competitive athlet it was inevitable that computers would be used for analysis of sports techniques. Computer calculations provide information that surpasses the limits of what

human eye can see and intuition can deduce. Human judgment, however, is still critically important. As in business and industry, where decisions are based ultimately upon an executive's experience and interpretive ability, the coach or trainer is, and will remain, the ultimate decision maker in athletic training. Rehabilitation and orthopedic specialists can assess impaired movement relative to normal performance and/or apply computerized biomechanical techniques to the possibilities of achieving the restoration of normal activities. With the increase in the population of older citizens, erotological applications will increase. The computer should be regarded as one more tool, however, complex, which can be skillfully used by humans in order to achieve a desired end.

One factor that humans have lived with is change. The environment in which we live is changing during every one of the ~ 35 million min of our lives. The human body itself changes from birth to maturity and from maturity to death. The moment humans first picked up a stone to use as a tool, the balance between humans and the environment was altered. After that adaptation, the ways in which the surrounding world changed resulted in different effects and these were no longer regular or predictable. New objects were created from things that otherwise would have been discounted. These changes were made possible by humans due to the invention of tools. The more tools humans created, the faster was the rate of environmental change. The rate of change due to tools has reached such a magnitude that there is danger to the whole environment and frequently to the people who use the tools, such as occurred during the Industrial Revolution, as well as in our own times with such problems as carpal tunnel syndrome. Human beings seem to have become so infatuated with their ability to invent things that they have concentrated almost exclusively upon improving the efficiency, safety, durability, cost, or aesthetic appeal of the device. It is ironic that with all of the innovative development, little consideration has been given to the most complex system with the most sophisticated computer in the world: the human body.

When they talk about their physical goals in work or in sports, people usually say they would like to do their best, meaning, reach their maximum output. It is a matter of achieving their absolute limit in speed, strength, endurance or skill and combining the elements with accuracy. This is no different than an athlete training for maximum performance in the Olympic games. The difficulty with focusing everything on maximum performance is that only a single goal, getting the highest results—fastest, biggest, quickest, longest, or most graceful—is considered a superlative or acceptable achievement. Maximums do not take into consideration other aspects of body performance that often prove to be just as important to the individual. Emphasis upon the demands for maximum performance is frequently portrayed with the thought that Winning isn't everything, it's the only thing. Figure 4 illustrates todays sophisticated biomechanical system to quantify human performance.

Imagine for a moment a maximum performance in the car industry—the perfect automobile. It is incredibly graceful and the aerodynamic, functional lines make it a thing of beauty. It accelerates from 0 to 60 miles $\cdot$ h^{-1} within a few

Figure 4. The modern biomechanical system.

seconds. It brakes, corners, and steers with a fineness that would permit a shortsighted 75-year old to compete at Le Mans. The suspension is so smooth that a passenger can pour liquids without spilling a drop. The car requires only minimal maintenance while averaging 50 miles $\cdot$ gal^{-1} in city driving. Best of all, it is the vehicle of the common man at a price of $5000. If all that sounds impossible—it is. Incorporating all of these maximums into a single automobile exceeds the ability of any designer or manufacturer. Instead, the individual shopping for a car must choose the attributes he or she feels are most important.

Therein lies the problem, some goals are partly, if not wholly, incompatible with others. An automatic transmission uses more gas than a standard shift, but it does make driving easier. Sleek aerodynamic lines add grace and reduce drag, but they can also lessen head room. High performance engines provide power, but require constant care. The solution is a compromise, a willingness to make tradeoffs.

This same spirit of compromise, of accepting something less than a single maximum, should govern the operation of the most important machine in our lives—our body. Reality must be applied when comparing ourselves to Olympic athletes or, with the progression of age, mimicking various youthful physical activities. For example, there is no need to have an endurance capacity equal to the current gold medalist or the strength level equivalent to the World heavyweight record holder. Likewise, senior citizens may resist relinquishing their drivers' licenses despite their slower reaction times, poorer eyesight, and/or hearing, as well as frequently suffering from some type of chronic disease that may further reduce their strength, joint mobility, or even cognitive processes, such as memory or decision making.

Instead of a maximum, what most people really want from their bodies is to optimize their performances and lives. They seek the most efficient use of energy, of bodily action consonant with productive output, health, and enjoyment. Many people are beginning to appreciate that certain types of exercise add to the vitality of the

cardiovascular system, lessen the risk of heart attack, and make it possible to live longer and more active lives. In other words, the willingness to sacrifice 20 yards on a drive off the golf tee may mean that the golfer's feet will be able to walk the entire course without being tortured during every step. The desire is to play a couple of hours of winning tennis, stroking the ball with pace and purpose, but not if the extra zing means a tennis elbow that will be sore for several weeks. Sensible joggers prefer to run 6 rather than 10 miles a day in 40 min, if the latter leads to tender knees and shin splints. In other words, human beings must compromise between anatomy (the structural components) and physiology (the bodily processes). A correct balance between the two, at all ages, will assist in optimizing bodily efficiency.

In addition to the desire for our internal environment to be physical fit, pertinent questions should be posed about our external environment. For example, is it really necessary for that designer chair to cause a bone ache deep in the buttocks after sitting for 5 min? Can a person not spend a day laboring over a desk or piece of machinery without feeling as if a rope had been tightly tied around the shoulders at the end of the project? Why must a weekend with shovel or rake inevitably produce lower back pain on Monday? Why is it that some individuals who are 50 years old seem able to work and play as if 10–20 years younger, while some 30 year olds act as if infected with a malignant decrepitude? The answer is that, as with the anatomy and physiology achieving optimal coordination, so should the whole human organism coordinate better with its environment.

Perhaps these examples could be dismissed as the minor aches of a hypochondriac society overly concerned with its comfort. But the overall health facts for the United States and many other modern civilizations appall even those jaded by constant warnings of disaster. The American Heart Association, in urging the 2005 Congress to fund prevention programs, contends that the Number One killer of Americans is heart disease, stroke, and other cardiovascular diseases. In addition, a total of 75 million Americans are afflicted with chronic disease. On any given day, >1 million workers do not show up for their jobs because of illness, and sickness prevents a million of these from returning in <1 week. Twenty-eight million Americans have some degree of disability. Perhaps not coincidentally, a quarter of the population is classified as overweight. At least 3 million citizens have diabetes, and one-half are unaware of the problem, and the United States accounts for most of the deaths due to cardiovascular disease. The health profile of the future, the condition of the youth of today, offers no comfort. About 1 in 5 youngsters still cannot pass even a simple test of physical performance. More than 9 million American children under the age of 15 have a chronic ailment. From one-third to one-half of U.S. children are overweight and one-third of America's young men fail to meet military physical fitness requirements.

In pursuit of technological achievement, Americans have almost ignored the one major element besides food and rest needed to sustain the human body: physical activity. This has lent impetus to a subtle yet deadly disease that has reached epidemic proportions in this country and others. Cardiovascular diseas referred to as hypokinetic disease or lack of-moti Unfortunately, degeneration with Americans lier rather than later. One study indicates that characteristics start to show at approximately peak age for heart disease among American years. In Europe, it is 10 years later. A corp employee health survey conducted by a large manufacturer indicated that smokers have 2 healthcare costs and 114% longer hospital nonsmokers. People who did not exercise have healthcare costs and 54% longer hospital stays t who did exercise. Overweight people have healthcare costs and 85% longer hospital stays t who are not. In general, people with poor hea have higher healthcare costs, longer hospital st productivity, more absenteeism, and more chro problems than those who do not. Some ques workers and their companies should ask are (1) heart attacks, strokes, cancers, or coronary by-p tions did your company pay for last year? (2) better would profits have been if heart diseases reduced 10, 20, or 30%? (3) How much would profits increase if employee healthcare costs we by 10%?

One large U.S. corporation developed a comp wellness program at numerous sites. During the grievances decreased by 50%, on-the-job acciden lost time by 40%, and sickness and accident pa 60%. The corporation estimated at least a 3:1 dollar invested.

The requirement for such an optimum way scientific analysis of the way people live and bodies. Only after such a quantitative examina concept of cost be determined or a better way something that is more efficient and less damag body, discovered. For example, rapid weight result from running long distances, such as 1 day, fasting drastically, or performing aerobics day. However, such excessive training regimens detrimental to the body as sitting all day in an and simply ignoring one's obesity.

Evolution, culture, and the changing demand tence have tended to develop forces and stresses body that are not necessarily in harmony with design and structure of the human equipment. upright, humans employ one pair of extremities f and the other pair capable of tremendous vers would seem that of all animals, humans, for assisted by the evolution of their brain and othe optimized the use of their body. Unfortunately, th body has had to pay a stiff price for its upright Human vertical posture is inherently unstable; humans must devote more neuromuscular effort trol to maintain balance, than four-legged anima is a tendency to lean forward, which adds to the move in that direction, but increases the risk of

A complex neuromuscular process is constantl to prevent humans from toppling. Many things m fere with this balancing act, such as consuming whiskey or walking on an icy sidewalk. These inte of the flow of information to and from the brain centre which coordinates the balancing process can result in staggering or falling. This postural condition creates a constant strain on all the muscles employed to retain balance and upon the set of bones forming the spine. The spine is basically a tower of I-beams supports the skeletal frame and, in order to remain in good health, proper mechanical alignment is essential. Any deviation from this mechanical alignment will result in pain relating to non-alignment, such as low back or neck pain. The vulnerability of the back is threatened frequently by work, recreation situations, and furnishings, since their uses subject an already tenuous upright position to undergo increased stresses. As the body compensates for alignment problems by creating excess bone tissue and neural pain, certain arthritic conditions may be the result.

Correction or prevention in tools or activities may assist in the optimization of performance and in more closely aligning the biological with the chronological age. Clearly, optimization and compensation may conflict within the human mechanism since a logical idea may violate physical principles. Based on this introduction of merely a few of the internal and external challenges to the human organism, the need for adequate and accurate assessments, improved tools, and human behavioral modifications becomes more apparent.

With each passing year, the composition of the population in America and probably many other modern societies is becoming older. This population increase of older citizens appears to be due, in part, to the large number of individuals of all ages who are experiencing modifications of lifestyle in a variety of ways, including better working conditions, improved health–medical opportunities, and changing activity levels. Pollock et al. (1) noted that the activity levels of elderly people have increased during the previous 20 years. However, it was estimated that only 10% of elderly individuals participate in regular vigorous physical activity and that 50% of the population who are 60 or more years of age described their lifestyles as sedentary.

Scientific studies and personal experiences continue to link many of the health problems and physical limitations found in the aged to lifestyle. Sedentary living appears to be a major contributor to the significantly adverse effect on health and physical well being. Certainly, there is increasing evidence indicating the vital need for improved national and international policies for better fitness, health, and sports for older individuals. In order to address some of these indicators, new attitudes and policies must emphasize activities and resources to meet the minimal requirements for keeping older people in good health, preventing their deterioration with age, and meeting the special interests of individuals with various disorders. In addition to the difficulties that hospitals, insurance companies, children of the elderly, and legislators face, the medical and scientific communities require time to determine the most appropriate solutions for improving the quality of these lengthening lives.

Many of the myths about aging are being disproved while the true nature of age-related changes appears to be less bleak than previously thought. Disuse and disease, not age alone, are increasingly, revealed as culprits. There is an increasing awareness of the need for more emphasis on fitness to maintain wellness and prevent degenerative illness, for more research to understand the aging body of the healthy older person, and to determine the exercise needs of the ill and/or the handicapped. Pollock et al. (1) noted that physical capacity decrements are normally associated with the aging process. This loss has been attributed to the influence of disease, medication, age, and/or sedentary lifestyle. Additionally, it was noted that the majority of the elderly do not exercise and that it is unclear whether the reduced state of physical conditioning associated with aging results from the deconditioning due to sedentary living, age, or both.

It is a fact of life that muscle tissue suffers some diminution from age. Age-associated changes in organ and tissue function, such as a decline in fat-free mass, total body and intracellular water, and an increase in fat mass (2) may alter the physiological responses to exercise or influence the effect(s) of medication. However, any discussion about age realistically utilizes arbitrary time periods apportioned eons ago by men who evaluated time relative to the number of revolutions of the earth around the sun and the rotation of the earth on its own axis. These predetermined periods may or may not have any relationship with the aging of the cells in the body. The linkage between the chronological age and the biological age of people is imprecise. Perhaps a more accurate consideration of the relationship between chronological and biological age would be one that is nonlinear, may differ with gender, or be dependent on other factors.

It is an inevitable evolutionary consequence that individuals within a species differ in many ways. The characterization of an individual on the basis of a chronological age scale may be practical, but biologically inappropriate. It may be that use or functional activities may have a greater influence on determining biological age rather than the number of times the earth has revolved around the sun. It appears that biological age can be affected by genetic code, nutrition and, most physical activity. Astrand (3) suggested that as an individual ages, the genetic code may have more of an effect on the function of systems with key importance in physical performance. He also noted that a change in lifestyle, at almost any chronological age, can definitely modify the biological age, either upward or downward. It has been suggested that the disparity of older persons is a hallmark of aging itself (4). It is important to determine how much age variance is due to the passage of time and how much is caused by the accumulation of other, nontime dependent, alterations. Previous attitudes towards physical adversities observed in the elderly were that they were attributable to disease. More recently, a third dimension associated with poor health in older persons has been described by Bortz and Bortz (4) as The Disuse Syndrome. For example, one of the most common markers of aging was thought to be a decreased lean body mass. However, analysis of 70 year old weight lifters revealed no such decline. The components of the Disuse Syndrome have been similarly grouped by Kraus and Raab (5) in their book, Hypokinetic Disease, and are (*1*) cardiovascular vulnerability; (*2*) musculoskeletal fragility; (*3*) obesity; (*4*) depression; (*5*) premature aging.

Use is a universal characteristic of life. When any part of the body has little or no use, it declines structurally and

functionally. The effects of disuse can be observed on any body part, such as atrophied intestinal mucosa, when a loop is excluded from digestive functions or the lung becomes atelectatic when not aerated. A lack of adequate conditioning and physical activity causes alterations in the heart and circulatory system, as well as the lungs, blood volume, and skeletal muscle (6–9). During prolonged bed rest, blood volume is reduced, heart size decreases, myocardial mass falls, blood pressure response to exercise increases, and physical performance capability is markedly reduced. On the other hand, although acute changes within the cardiovascular system result in response to increased skeletal muscle demands during exercise, there is evidence that chronic endurance exercise produces changes in the heart and circulation that are organic adaptations to the demands of chronic exercise (10–15).

Cardiac performance undergoes direct and indirect age-associated changes. There is a reduction in contractility of the myocardium (16) and this increased stiffness impairs ventricular diastolic relaxation and increases end diastolic pressure (17). This suggests that exercise-induced increases in heart rate would be less well tolerated in older individuals than in younger populations. The decline in maximal heart rate is known and the cause is multifactorial, but is mostly related to a decrement in sympathetic nervous system response. Fifty percent of Americans who are >65 years of age have a diagnostically abnormal resting electrocardiogram (18). Another factor associated with aging is a progressive increase in rigidity of the aorta and peripheral arteries due to a loss of elastic fibers, increase in collagenous materials, and calcium deposits (19). When aortic rigidity increases, the pulse generated during systole is transmitted to the arterial tree relatively unchanged. Therefore, systolic hypertension predominates in elderly hypertensive patients.

Other bodily systems demonstrate age-related alterations. Baroreceptor sensitivity decreases with age and hypertension (20,21) such that rapid adjustment of the cerebral circulation to changes in posture may be impaired. Kidney function reveals a defect in renal concentrating ability and sluggish renal conservation of sodium intake causes elderly patients to be more susceptible to dehydration (22). Hyaline cartilage on the articulator surface of various joints shows degenerative changes and clinically represents the fundamental alteration in degenerative osteoarthritis (23). A decrease in bone mineral density (osteoporosis) can reduce body stature as well as predispose the individual to spontaneous fractures. Older women are more prone to osteoporosis than older men and this may reflect hormonal differences (23). Older persons are less tolerant of high ambient temperatures than younger people (24) due to a decrease in cardiovascular and hypothalamic function which compromises the heat dissipating mechanisms. Heat dissipation is further compromised by the decrease in fat-free mass, intracellular and total body water, and an increase in body fat.

Unfortunately, the effects of disuse on the body manifest themselves slowly since humans normally have redundant organs that can compensate for ineffectiveness or disease. In addition, humans are opaque so that disease or deterioration are externally unobservable and, thus, go unheeded (e.g., the early changes in bones due to porosis are subclinical and are normally detected on becoming so pronounced that fractures ensue). Cur et al. (25) mentioned the difficulty of distinguishin ifestations in musculoskeletal changes due to related to aging. Muscle mass relative to total bod begins decreasing in the fifth decade and becomes edly reduced during the seventh decade of life. This results in reduced muscular strength, endurance, well as a reduction in the number of muscle Basmajian and De Luca (26) reported numerous tions in the electrical signals associated with vol muscular contractions with advancing age. As yet, are no findings published that have definitively age-related musculoskeletal changes in either the n or the muscular system. The diaphragm and cardia cle do not seem to incur age changes. Perhaps this is constant use, from exercise, or possibly a genetic su mechanism.

There is growing consensus that many illness preventable by good health practices including ph exercise. Milliman and Robertson (27) reported that, 15,000 employees of a major computer company, th exercisers accounted for 30% more hospital stays th exercisers. Lane et al. (28) reported that regular ru had only two-thirds as many physician visits as comm matched controls. The beneficial effect of exercise o betes has long been recognized and is generally r mended as an important component in the treatm diabetes (29). Regular endurance exercise favorably coronary artery disease risk factors, including hyp sion, triglyceride and high density lipoprotein chole concentrations, glucose tolerance, and obesity. In add regular exercise raises the angina threshold (30).

Jokl (31) suggested three axioms of gerontology th affected by exercise. He contents that sustained tra results in the following: (*1*) decline of physique with ag decline of physical fitness with age; (*3*) decline of m functions with age.

Health in older people is best measured in terms of tion, mental status, mobility, continence, and a ran activities of daily living. Preventive strategies appear able to forestall the onset of disease. Whether exercis prevent the development of atherosclerosis, delay the o rence of coronary artery disease, or prevent the evoluti hypertension is at present debatable. But moderate en ance exercise significantly decreases cardiovascular tality (32). Endurance exercise can alter the contribut of stress, sedentary lifestyle, obesity, and diabetes to development of coronary artery disease (33).

For example, the four-time Olympic discus champio Oerter, at the age of 43, focused his training to qualif the 1980 Olympic Games that would have been his consecutive Olympiad Oerter threw his longest throw [(67.05 m)] but, since the United States boycotted the Moscow Olympic Games, his chance was denied. By time of the 1984 Los Angeles Games, Oerter was 47 y old. Even at an age well beyond most Olympic competit he again threw his best, exceeding 240 f (73.15 m) in prac sessions. Oerter's physique and strength suggested that biological age was less than his chronological

Biologically, he was probably between 25 and 30, although chronologically he was 15–20 years older. Unfortunately, in the competition that determined which athletes would represent the United States, Oerter suffered an injury that precluded him from trying to achieve an unprecedented fifth consecutive Olympic Gold medal.

PRINCIPLES FOR EXERCISE AND TRAINING

Physical fitness and exercise have become, as previously discussed, an increasing concern at nearly all levels of American society. The goal of attaining peak fitness has existed for centuries, yet two problems continue to obfuscate understanding. The ability to assess strength and/or to exercise has occupied centuries of thought and effort. For examples, Milo the Greek lifted a calf each day until the baby grew into a bull. Since this particular procedure is not commonly available, humans have attempted to provide more suitable means to determine strength levels and ways to develop and maintain conditioning. Technology for assessing human performance in exercise and fitness evaluations, in both theory and practice, exhibits two problems. First, a lack of clearly defined and commonly accepted standards results in conflicting claims and approaches to both attaining and maintaining fitness. Second, a lack of accurate tools and techniques for measuring and evaluating the effectiveness of a given device designed to diagnose present capabilities for exercising or even to determine which exercises are appropriate to provide "fitness", regardless of age or gender. Vendors and consumers of fitness technology have lacked sound scientific answers to simple questions regarding the appropriateness of exercise protocols.

Reviewing studies conducted to determine the effects of strength training on human skeletal muscle suggests many benefits with appropriate exercise. In general, strength training that uses large muscle groups in high resistance, low repetition efforts increases the maximum work output of the muscle group stressed (34). Since resistance training does not change the capacity of the specific types of skeletal muscle fibers to develop different tensions, strength is generally seen to increase with the cross-sectional area of the fiber (35). The human body can exercise by utilizing its own mass (e.g., running, climbing, sit ups). These and other forms of nonequipment based exercises can be quite useful. In addition, there are various types of exercise equipment that allow selection of a weight or resistance and then the exercise against that machine resistance is performed.

The relationship between resistance exercises and muscle strength has been known for centuries. Milo the Greek's method of lifting a calf each day until it reached its full growth probably provides the first example of progressive resistance exercises. It has been well-documented in the scientific literature that the size of skeletal muscle is affected by the amount of muscular activity performed. Increased work by a muscle can cause that muscle to undergo compensatory growth (hypertrophy), whereas disuse leads to wasting of the muscle (atrophy).

The goal of developing hypertrophy has stimulated the medical and sports professions, especially coaches and ath-

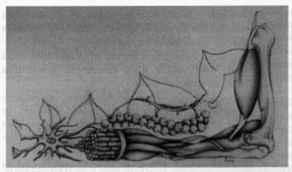

Figure 5. Integration of our muscular system.

letes, to try many combinations and techniques of muscle overload. Attempts to produce a better means of rehabilitation, an edge in sporting activities, as a countermeasure for the adverse effects of space flight, or as a means to improve or enhance bodily performances throughout a lifetime have only scratched the surface of the cellular mechanisms and physiological consequences of muscular overload.

Muscular strength can be defined as the force that a muscle group can exert against a resistance in a maximal effort. In 1948, Delorme and Watkins (36) adopted the name "progressive resistance exercise" for his method of developing muscular strength through the utilization of counter balances and weight of the extremity with a cable and pulley arrangement. This technique gave load-assisting exercises to muscle groups that did not perform antigravity motions. McQueen (37) distinguished between exercise regimes for producing muscle hypertrophy and those for producing muscle power. He concluded that the number of repetitions for each set of exercise determines the different characteristics of the various training procedures. Figure 5 illustrates the complexity of the skeletal–muscular structure.

When muscles contract, the limbs may appear to move in unanticipated directions. One type of motion is a static contraction, known as an isometric type of contraction. Another type of contraction is a shortening or dynamic contraction that is called an isotonic contraction. Dynamic contractions are accompanied by muscle shortening and by limb movement. Dynamic contractions can exhibit two types of motion. One activity is a concentric contraction in which the joint angle between the two bones become smaller as the muscular tension is developed. The other action is an eccentric contraction in which, as the muscles contract, the joint angle between the bones increases. Owing to ambiguity in the literature concerning certain physiologic terms and differences in laboratory procedures, the following terms are defined below.

1. *Muscular strength*: the contractile power of muscles as a result of a single maximum effort.
2. *Muscular endurance*: ability of the muscles to perform work by holding a maximum contraction for a given length of time or by continuing to move submaximal load to a certain level of fatigue.

3. *Isometric*: a muscular contraction of total effort but with little or no visible limb movement (sometimes referred to as static or anaerobic).
4. *Isotonic*: a muscular contraction of less than total effort with visible limb movement (sometimes called dynamic or aerobic).
5. *Isokinetic training (accommodating resistance)*: muscular contraction at a constant velocity. In other words, as the muscle length changes, the resistance alters in a manner that is directly proportional to the force exerted by the muscle.
6. *Concentric contraction*: an isotonic contraction in which the muscle length decreases (that is, the muscle primarily responsible for movement becomes shorter).
7. *Eccentric contraction*: an isotonic contraction in which the muscle length of the primary mover and the angle between the two limbs increases during the movement.
8. *Muscle overload*: the workload for a muscle or muscle group that is greater than that to which the muscle is accustomed.
9. *Variable resistance exercise*: as the muscle contracts, the resistance changes in a predetermined manner (linear, exponentially, or as defined by the user).
10. *Variable velocity exercise*: as the muscle contracts with maximal or submaximal tension, the speed of movement changes in a predetermined manner (linear, exponentially, or as defined by the user).
11. *Repetitions*: the number of consecutive times a particular movement or exercise is performed.
12. *Repetition maximum (1 RM)*: the maximum resistance a muscle or muscle group can overcome in a maximal effort.
13. *Sets*: the number of groups of repetitions of a particular movement or exercise.

Based on evidence presented in these early studies (36–38), hundreds of investigations have been published relative to techniques for muscular development, including isotonic exercises, isometric exercises, eccentric contractions, and many others. The effectiveness of each exercise type has been supported and refuted by numerous investigations, but no definitive, irrefutable conclusions have been established.

Hellebrandt and Houtz (38) shed some light on the mechanism of muscle training in an experimental demonstration of the overload principle. They found that the repetition of contractions that place minimal stress on the neuromuscular system had little effect on the functional capacity of the skeletal muscles. They also found that the amount of work done per unit of time is the critical variable upon which extension of the limits of performance depends. The speed with which functional capacity increases suggests that the central nervous system, as well as the contractile tissue, is an important contributing component of training.

Results from the work of Hellebrandt and Houtz (3 suggest that an important consideration in both the desi of equipment for resistive exercise and the performance an athlete or a busy executive is that the human body reli on preprogrammed activity by the central nervous syste Since most human movements are ballistic and the neur control of these patterns differs from slow controlled mov ments, it is essential that training routines employ pr grammable motions to suit specific movements. Th control necessitates exact precision in the timing a coordination of both the system of muscle contracti and the segmental sequence of muscular activity. Resear has shown that a characteristic pattern of motion is pr sent during any intentional movement of body segmen against resistance. This pattern consists of reciprocal organized activity between the agonist and antagoni These reciprocal activities occur in consistent tempor relationships with the variables of motion, such as velocit acceleration, and forces.

In addition to the control by the nervous system, t human body is composed of linked segments, and rotati of these segments about their anatomic axes is caused force. Both muscle and gravitational forces are important producing these turning effects, which are fundamental body movements in all sports and daily living. Pushin pulling, lifting, kicking, running, walking, and all hum activities result from the rotational motion of the links whic in humans, are the bones. Since force has been considered t most important component of athletic performance, ma exercise equipment manufacturers have developed vario types of devices employing isometrics and isokinetics. Wh considered as a separate entity, force is only one fact influencing successful athletic performance. Unfortunatel these isometric and isokinetic devices inhibit the natur movement patterns of acceleration and deceleration.

The three factors underlying all athletic performanc and the majority of routine human motions are forc displacement, and the duration of movement. In all mot skills, muscular forces interact to move the body par through the activity. The displacement of the body par and their speed of motion are important in the coordinati of the activity and are also directly related to the forc produced. However, it is only because of the control pr vided by the brain that the muscular forces follow a particular displacement pattern and, without these bra centre controls, there would be no skilled athletic perf mances. In every planned human motion, the intrica timing of the varying forces is a critical factor in successf performances. In any human movement, the accura coordination of the body parts and their velocities is esse tial for maximizing performances. This means that t generated muscular forces must occur at the right tin for optimum results. For this reason, the strongest weig tlifter cannot put the shot as far as the experienced sh putter, although the weightlifter possesses great muscular force, he has not trained his brain centers produce the correct forces at the appropriate time. Old individuals may be unable to walk up and down stairs perform many of the daily, routine functions that had bee virtually automatic before the deterioration produced weakness, disease, or merely age.

There are significant differences in the manner of execution of the various resistive training methods. In isotonic exercises, the inertia, which is the initial resistance, must be overcome before the execution of the movement progresses. The weight of the resistance cannot be heavier than the maximum strength of the weakest muscle acting in a particular movement or the movement cannot be completed. Consequently, the amount of force generated by the muscles during an isotonic contraction does not maintain maximum tension throughout the entire range of motion. In an isokinetically loaded muscle, the desired speed of movement occurs almost immediately and the muscle is able to generate a maximal force under a controlled and specifically selected speed of contraction.

The use of the isokinetic principle for overloading muscles to attain their maximal power output has direct applications in the fields of sport medicine and athletic training. Many rehabilitation programmed utilize isokinetic training to recondition injured limbs of athletes to their full range of motion. The unfortunate drawback to this type of training is that the speed is constant and there are no athletic activities that are performed at a constant velocity. The same disadvantage applies to normal human activities.

In isotonic resistive training, if more than one repetition is to be used, a submaximal load must be selected for the initial contractions in order to complete the required repetitions. Otherwise, the entire regimen would not be completed, owing to fatigue or, the inability to perform. A modality that can adjust the resistance so that it parallels fatigue to allow a maximum effort for each repetition would be a superior type of equipment. This function could be accomplished by manually removing weight from the bar while the subject trained. This is neither convenient nor practical. With the aid of the computer, the function can be performed automatically.

Another drawback with many isotonic types of resistive exercises is that the inertia resulting from the motion changes the resistance depending on the acceleration of the weight and of the body segments. In addition, since overload on the muscle changes due to both biomechanical levers and the length–tension curve, the muscle is able to achieve maximal overload only in a small portion of the range of motion. To overcome this shortcoming in resistive training, some strength training devices have been introduced that have "variable resistance" mechanisms, such as a cam, in them. However, these variable resistance systems increase the resistance in a linear fashion and this linearity may not truly accommodate the individual. When including inertial forces to the variable resistance mechanism, the accommodating resistance can be canceled by the velocity of the movement.

There seem to be unlimited training methods and each is supported and refuted by as many "experts". In the past, the problem of accurately evaluating the different modes of exercise was rendered impossible because of the lack of adequate diagnostic tools. For example, when trying to evaluate isotonic exercises, the investigator does not know exactly the muscular effort nor the speed of movement, but knows only the weight that has been lifted. When a static weight is lifted, the force of inertia provides a significant contribution to the load and cannot be quantified by feel or observation alone. In the isokinetic mode, the calibration of the velocity is assumed, but has been poorly verified since the mere rotation of a dial to a specific speed setting does not guarantee the accuracy of subsequently generated velocity. In fact, discrepancies as great as 40% have been observed when verifying the bar velocity.

Most exercise equipment currently available lack intelligence. In other words, the equipment is not aware that a subject is performing an exercise or how it is being conducted. Verification of the speed is impossible since a closed-loop feedback and sensors are absent. However, with the advent of miniaturized electronics in computers, it became possible to unite exercise equipment with the computer's artificial intelligence. In other words, it became possible for exercise equipment to adapt to the user rather than forcing the user to adapt to the equipment.

HIGH TECHNOLOGY TOOLS

High technology refers to the use of advanced, sophisticated, space age mathematical and electronic methods and devices for creating tools that can enhance human activities as well as expanding the horizons for future inventions. NASA put a man on the moon, sent exploratory spacecraft to Mars and beyond, and is sending shuttle missions to the Space Station. Polymer science invented plastics, mechanical science produced the automobile, and aeronautical engineering developed the airplane. Despite all of the knowledge and explosive developments since the rock became a tool, few advances have considered first the most important component in a complicated system, the human body.

The usual developmental cycle creates something and humans must adapt to it rather than the reverse. Computers can provide precise computations rapidly for complex problems that would otherwise require enormous quantities of time, talent, and energy to complete. The strength of these electronic wizards to follow instructions exactly, remember everything, and perform calculations within thousandths of a second has made them indispensable in finance, industry, and government. Application of the computer was a perfect enhancement for the human mind in order to quantify and evaluate movement performances. Used in conjunction with the human mind's ability to deduce, interpret, and judge, the computer provides the necessary enhancement to surpass the limits of what the eye can see or what intuition can surmise. Technological advances, such as these, can assist humans irrespective of their age.

For good health, it is necessary to follow a training method that incorporates all of the various bodily systems. In other words, the body should be treated as a complex, but whole, entity rather than as isolated parts. While it is not wrong to evaluate one's diet, an assessment of health would be incomplete without consideration of physical training, stress reduction, and other components that constitute the integrated organism of the human body. For a person to be able to jog 5 miles it is not important only to

run, but to develop the cardiovascular system in a systematic way to achieve a healthy status. Strength exercise, flexibility routines, proper nutrition and skill are necessary to achieve this goal.

Two sophisticated systems have been developed to analyze human performance and both are appropriate for the assault on aging. These systems include tools to (*1*) assess movements of the human body and (*2*) assist in exercising human beings. The first one is the biomechanical system that was developed to analyze movement performance. Currently, biomechanical analyses are routinely performed on a wide range of human motions in homes, work settings, recreation, hospitals, and rehabilitation centers. The second system, which incorporates space age technology, allows diagnoses and training of the musculoskeletal system. Each of these systems will be discussed subsequently in detail. Both of these technologies and the scientific principles and techniques discussed may help achieve physical and mental goals. The technological advances provide tools for quantification of the results and to analyze the potential of a person. With this information and these tools, it should be possible to train the various body systems for optimal results at any age.

The first commercially available computerized biomechanical system was described in 1973 (39) and that system can serve to illustrate the general concepts and procedures associated with biomechanical quantification of movement. Figure 6 illustrates device system. The computerized hardware–software system provides a means to objectively

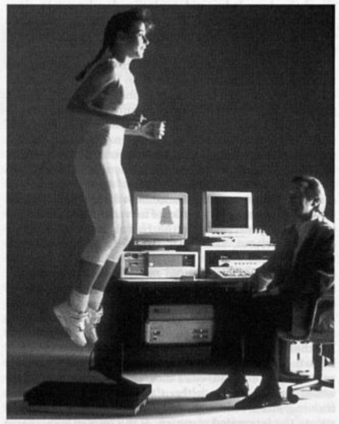

Figure 6. Analyses of vertical jump.

quantify the dynamic components of movemen
such as athletic events, gait analyses, work ac
as motion by inanimate objects, including s
machinery actions, air bag activation, and
dummies. This objective technique replaces n
tion and supposition. This system provides
quantity motion utilizing input information
all of the following mediums: visual (video)
graphy (EMG), force platforms, or other sign
diagnostic equipment.

The Ariel Performance Analysis System
means of measuring human motion based on
technique for the processing of multiple high
recordings of a subject's performance (40–42
nique demonstrates significant advantages ov
mon approaches to the measurement
performance. First, except in those specific
requiring EMG or kinetic (force platform) da
invasive. No wires, sensors, or markers need b
the subject. Second, it is portable and does
modification of the performing environment.
be taken to the location of the activity and posi
convenient manner so as not to interfere with
Activities in the workplace, home, hospita
office, health club, or athletic field can be
equal ease. Third, the scale and accuracy of r
can be set to whatever levels are required fo
being performed. Camera placement, lens se
ter and film speed may be varied within w
collect data on motion of only a few centimete
meters, with a duration from a few millis
number of seconds. Video equipment technolo
available is sufficiently adequate for most
requiring accurate motion analysis. Determi
problem, error level, degree of quantificatio
affect the input device selection.

A typical kinematic analysis consists of
phases: data collection (filming); digitizing;
and presentation of the results. Data collectio
phase that is not computerized. In this phase,
ings of an activity are made using two or m
with only a few restrictions: (*1*) all cameras mu
action simultaneously. (*2*) If a fixed camera is
not move between the recording of the acti
recording of the calibration points. These lin
are not necessary when a panning camera an
mechanism are used. A specialized device acc
specialized software was developed to accom
era movement particularly for use with gait
some longer distance sporting events, such as
jumping. (*3*) The activity must be clearly seen
its duration from at least two camera views.
tion of at least six fixed noncoplanar points
each camera view (calibration points) mus
These points need not be present during th
long as they can be seen before or after the acti
they are provided by some object or apparat
dimensions that is placed in the general area o
filmed and then removed. (*5*) The speed of
cameras (frames/second) must be accura
although the speeds do not have to be identi

Figure 7. Digitizing system.

event or time signal must be recorded simultaneously by all cameras during the activity in order to provide synchronization.

These rules for data collection allow great flexibility in the recording of an activity. Figure 7 illustrates a modern digitizing system to quantify human movement. Information about the camera location and orientation, the distance from camera to subject, and the focal length of the lens is not needed. The image space is self-calibrating through the use of calibration points that do not need to be present during the actual performance of the activity. Different types of cameras and different film speeds can be used and the cameras do not need to be mechanically or electronically synchronized. The best results are obtained when camera viewing axes are orthogonal (90° apart), but variations of 20–30° can be accommodated with negligible error. Initially, the video image is captured by the computer and stored in memory. This phase constitutes the "Grabbing" mode. Brightness, contrast, saturation, and color can be adjusted so that the grabbed picture may, in fact, be better than the original. Grabbing the image and storing it on computer memory eliminates any further need for the video apparatus.

Digitizing is the third step in biomechanical quantification. The image sequence is retrieved from computer memory and displayed, one frame at a time, on the digitizing monitor. Using a video cursor, the location of each of the subject's body joints (e.g., ankle, knee, hip, shoulder, elbow) is selected and stored in computer memory. In addition, a fixed point, which is a point in the field of view that does not move, is digitized for each frame as an absolute reference. The fixed point allows for the simple correction of any registration or vibration errors introduced during recording or playback. At some point during the digitizing of each view, a synchronizing event must be identified and, additionally, the location of the calibration points as seen from that camera must be digitized. This sequence of events is repeated for each camera view. This type of digitizing is primarily a manual process.

An alternative digitizing option permits the procedure to proceed automatically using any number of marker sets. This requires that the subject have the markers placed on the body prior to the filming phase. The types of markers and their placements have a substantial number of adherents particularly in the rehabilitation, gait measurement, and computer game communities. This type of digitizing combines manual and automatic, so that the activity progresses under manual control with computer-assisted selection of the joint segments or points. User participation in the digitizing process provides an opportunity for error checking and visual feedback which rarely slows the digitizing process adversely. A trained operator, with reasonable knowledge about digitizing and anatomy, can rapidly produce high quality digitized images. It is essential that the points are selected precisely because all subsequent information is based on the data provided in this phase.

The computation phase of analysis is performed after all camera views have been digitized. At this point in the procedures, the three-dimensional (3D) coordinates of the joints centers of a body are calculated. The transformation methods for transforming the data to two-dimensional (2D) or 3D coordinates are Direct Linear Transformation, Multiplier, and Physical Parameters Transformation. This phase computes the true 3D image space coordinates of the subject's body joints from the 2D digitized coordinates obtained from each camera's view. The Direct Linear Transformation Computation is determined by first relating the known image space locations of the calibration points to the digitized coordinate locations of those points. The transformation is then applied to the digitized body joint locations to yield true image space locations. This process is performed under computer control with some timing information provided by the user. The information needed includes, for example, starting and ending points if all the data are not to be used, as well as a frame rate for any image sequence that differs from the frame rate of the cameras used to record the sequence. The Multiplier technique for transformation is less rigorous mathematically and is utilized for those situations when no calibration device was used and only a few objects in the background are available to calibrate the area. This situation usually occurs when a nonscientific, third-party recorded the pictures such as a home video or even a televised sporting event. The third type of transformation, the Physical Parameters Transformation, is primarily applied with panning camera views or when greater accuracy is required on known image sources.

Following data transformation, a smoothing or filtering operation is performed on the image coordinates to remove small random digitizing errors and to compute body joint

velocities and accelerations. Smoothing options include polynomial, cubic and quintic splines, a Butterworth second-order digital and fast Fourier filters (43–45). Smoothing may be performed automatically by the computer or interactively with the user controlling the amount of smoothing applied to each joint. Error measurements from the digitizing phase may be used to optimize the amount of smoothing selected. Another unique feature is the ability to display the Power Spectrum for each of the x, y, and z coordinates. This enhancement permits the investigator to evaluate the effect of the smoothing technique and the chosen value selected for that curve by examining the Power Spectrum. Thus, the investigator can determine the method and level of smoothing that best meets the requirements of the specific research. After smoothing, the true 3D body joint displacements, velocities, and accelerations will have been computed on a continuous basis throughout the duration of the sequence.

Analogue data can be obtained from as many as 256 channels for input into the analogue-to-digital (A/D) system. Processing of the analogue signals, such as those obtained from transducers, thermistors, accelerometers, force platforms, EMG, ECG, EEG, or others, can be recorded for analysis and, if needed, synchronized with the video system. The displayed video picture and the vectors from the force plate can be synchronized so that the force vectors appear to be "inside the body". At this point, optional kinetic calculations can be performed to provide for measurement and analysis of the external forces that are applied to the body during movement. Inverse Dynamics are used to compute joint forces and torques as well as energy and momentum parameters of single or combined segments. External forces include anything external to the body that is applying force or resistance such as a golf club held in the hand. The calculations that are performed are made against the force distribution of the body.

The presentation phase of analysis allows computed results to be viewed and recorded in a number of different formats. Body position and motion can be presented in both still frame and animated stick figure format in 3D. Multiple stick figures may be displayed simultaneously for comparison purposes. Joint velocity and acceleration vectors may be added to the stick figures to show the magnitude and direction of body motion parameters. Copies of these displays can be printed for reporting and publication. Results can also be reported graphically. Plots of body joints and segments, linear and angular displacements, velocities, accelerations, forces, and moments can be produced in a number of format options. An interactive graphically oriented user interface allows the selection and plotting of such results to be simple and straightforward. In addition, body motion parameter results may also be reported in numerical form and printed as tables.

Utilizing this computerized system for biomechanical quantification of various movements performed by the elderly may assist in developing strategies of exercise, alterations in lifestyle, modifications in environmental conditions, and inventions to ease and/or extend independence. For example, rising from a chair is a challenging task for many elderly persons and getting up quickly is

associated with a particularly high risk for falling. H
Marcus (46) observed that older women moved more
and altered their posture to a greater extent than y
women. The strength levels were greater for the y
subjects, but it could not be concluded that streng
the causal mechanism for the slower speed. Follow
exercise program affecting a number of muscle
younger and older women significantly increa
strength. Results of this study suggest that age-ass
changes in muscle strength have an important ef
movement strategies used during chair rising. Fo
participation in a strength-training program, biom
cal assessment revealed changes in movement str
that increased both static and dynamic stability.
areas appropriate for biomechanical assessment w
on the well-known phenomenon of increased postur
(47) and problems with balance (48–50) in the age

It is also important to study the motor patterns
older persons while performing locomotor tasks ass
with daily life such as walking on level ground and
ing or descending stairs. Craik (51) demonstrate
older subjects walking at the same speed as young
exhibited similar movement characteristics. Perha
older subjects selected slower movement speeds th
duced apparent rather than real reductions in
mance. These types of locomotors studies are
assessed by biomechanical procedures. A biomec
inquiry by Williams (52) examined the age-related
ences of intralimb coordination by young and old
duals. Williams observed a similarity of general int
coordination for both old and young participants f
ground motions. One age-related change was sug
with regard to the additional balance constraints r
for going up stairs because of adjustments not requ
level ground. More profound differences were ob
by Light et al. (53) with complex, multilimb coord
movements performed in a standing position which
sitated dynamic balance control. These types of
showed significant age-dependent changes. Com
with younger subjects, the older participants were
in all timing components, had less predominance i
movement patterns, less coupling of their limbs for
ment end-points, and were more susceptible to e
mental uncertainties. The alterations in mov
performance reflected age-related loss in the ab
coordinate fast, multilimb movements performe
an upright stance suggesting that older individua
have uncoordinated and unpredictable movement p
when required to move quickly. Additionally, it w
gested that the more uncertain the environmen
greater the disturbance on the movement, thus, incr
the risk of falling. These studies provide realistic ex
of one role biomechanics can perform by not only
cally identifying the locus of change but also pro
objective quantification.

Another interesting application of the biomech
system involves a multidimensional study of Alzhe
disease currently in progress at a leading medical
The study's strength is similar to the blind men wh
integrate all of the information each has gathered i
to accurately describe the elephant. Examination

ain's response to specific drugs and at varying dosages, agnetic resonance imaging (MRI), thermographic, endo- rine, and hormonal changes, vascular chemistry, as well s other aspects are being evaluated for each patient and eir specific motor performances are being quantified mechanically with the Ariel Performance Analysis sys- m. Preliminary evidence indicates that performance on a mple bean-bag tossing skill improves daily although ere is no cognitive recognition of the task. The activity f tossing a bean bag into a target circle from a standing sition employs postural adjustments as well as coordi- ated arm and hand directed skills. Skill acquisition, or otor learning, involves both muscular capability and eural control mechanisms. Both activities involve closed- nd open-loop mechanisms. The goal-directed movements eeded to perform the bean-bag toss require the anticipa- ary postural adjustments that are inherent in an open- op control. Because these findings suggest that muscular ntrol and skill acquisition remain viable, this enables vestigators to narrow the direction of the research and ntinue the study while continuously honing the focus. ith each scientific finding, the research can be directed ward identification of the underlying cause.

The preceding discussion has described a computerized mechanical system that can be utilized for the quanti- cation of activities and performance levels particularly ere appropriate for gerontological issues. Following the entification and definition of an activity, a second and ually necessary component follows. This is the ability to aluate, test, and/or train the musculoskeletal compo- nts of the body in a manner appropriate to the specifi- lly identified task(s) and according to the capabilities of e age and health of the individual. The integration of th technological assessment tools should assist the indi- dual and others involved in their daily life to identify and easure those portions of an exercise program that can hance performance, fitness status, or exercise capabil- es for each gender and at different ages. In other words, e of the principles should be remembered is the goal of timizing performance at every age.

For centuries, many devices have been created specifi- lly for strength development. These devices include eadmills, bicycle ergometers, rowing machines, skiing mulators, as well as many of the more traditional resis- e exercises with dumbbells, bar bells, and commercially ailable weight equipment. Figure 8 illustrates one of ese equipment. Each type of exercise has some advan- ges, but none are designed to cope with the difficulties herent with the gravitational effects that affect the ltilinked human body performing on various exercise uipment.

All systems that employ weights as the mechanism for istance have major drawbacks in four or more areas, as lows: (1) biomechanical considerations; (2) inertia; (3) k of injury; (4) unidirectional resistance.

The biomechanical parameters are extremely important human performance and should be incorporated into ercise equipment. The biomechanical factors were dis- sed previously. Inertia is the resistance to changes in tion. In other words, a greater force is required to begin ving weights than is necessary to keep them moving.

Figure 8. The computerized exercise equipment.

Similarly, when the exercising person slows at the end of a movement, the weights tend to keep moving until slowed by gravity. This phenomenon reduces the force needed at the end of a motion sequence. Inertia becomes especially pronounced as acceleration and deceleration increase, effectively reducing the useful range of motion of weight-based exercise equipment.

The risk of injury is obvious in most weight-based exercise equipment. When weights are raised during the performance of an exercise, they must be lowered to their original resting position before the person using the equipment can release the equipment and stop exercising. If the person exercising loses their grip, or is unable to hold the weights owing to exhaustion or imbalance, the weights fall back to their resting position; serious injuries can, and have, occurred. Finally, while being raised or lowered, weights, whether on exercise equipment or free standing, offer resistance only in the direction opposite to that of gravity. This resistance can be redirected by pulleys and gears but still remains unidirectional.

In almost every exercise performed, the muscle or muscles being trained by resistance in one direction are balanced by a corresponding muscle or muscles that could be trained by resistance in the opposite direction. With weight-based systems, a different exercise, and often a different mechanism, is necessary to train these opposing muscles. Exercise mechanisms that employ springs, torsion bars, and the like are able to overcome the inertia problem of weight-based mechanisms and, partially, to compensate the unidirectional force restriction by both expanding and compressing the springs. However, the serious problem of safety remains. An additional problem is the fixed, nonlinear resistance that is characteristic of springs and is usually unacceptable to most exercise equipment users.

The third resistive mechanism commonly employed in existing exercise equipment is a hydraulic mechanism. Hydraulic devices are able to overcome the inertial problem of weights, the safety problem of both weights and springs, and, with the appropriate selection or configuration, the unidirectional problem. However, previous applications of the hydraulic principle have demonstrated a serious

deficiency that has limited their popularity in resistive training. This deficiency is that of a fixed or a preselected flow rate through the hydraulic system. With a fixed-flow rate, it is a well established fact that resistance is a function of the velocity of the piston and, in fact, varies quite rapidly with changes in velocity. It becomes difficult for a person exercising to select a given resistance for training due to the constraint of moving either slower or faster than desired in order to maintain the resistance. Additionally, at any given moment, the user is unsure of just what the performing force or velocity actually is.

In the field of rehabilitation (54) especially, isokinetic or constant velocity training equipment is a technology that has enjoyed wide acceptance. These mechanisms typically utilize active or passive hydraulics or electric motors and velocity-controlling circuitry. The user or practitioner selects a constant level of velocity for exercise and the mechanism maintains this velocity while measuring the force exerted by the subject. Although demonstrating significant advantages over weight-based systems, isokinetic systems possess a serious limitation. There are virtually no human activities that are performed at a constant velocity. Normal human movement consists of patterns of acceleration and deceleration. When a person learns to run, ride a bike, or write, an acceleration–deceleration sequence is established that may be repeated at different rates and with different levels of force, but always with the pattern unique to that activity. To train, rehabilitate, or diagnose at a constant velocity is to change the very nature of the activity being performed and to violate most biomechanical performance principles.

FEEDBACK CONTROL OF EXERCISE

A newer form of exercise equipment can determine the level of effort by the person, compare it to the desired effort, and then adjust accordingly. The primary advantage of this resistive mechanism is that the pattern of resistance or the pattern of motion is fully programmable. The concept of applying a pattern of resistance or motion to training and rehabilitation was virtually impossible until the invention of computerized feedback control. Prior to the introduction of computerized feedback control, fitness technology could provide only limited modes of resistance and motion. Bar bells or weights of any type provide an isotonic or constant resistance type of training only when moved at a constant velocity. Typically, users are instructed to move the weights slowly to avoid the problem of inertia resulting from the acceleration or deceleration of mass. Weights used with cams or linkages that alter the mechanical advantage can provide a form of variable resistance. However, the pattern is always fixed and the varying mechanical advantage causes a variation in velocity that increases inertial effects. Users must move the weights slowly to preserve the resistance pattern. Another deficiency with these types of equipment is that they do not approximate the body or limb movement pattern of a normal human activity.

An exercise machine controlled by a computer possesses several unique advantages over other resistive exercise mechanisms, both fixed and feedback controlled. The most significant of these advances is the introduction of software to the human/computer feedback loop. The computer and its associated collection of unique programs can regulate the resistance to vary with the measured variables of force and displacement as well as modify the resistance according to data obtained from the feedback loop while the exercise progresses. This modification can, therefore reflect changes in the pattern of exercise over time. The unique programmed selection can effect such changes in order to achieve a sequential or patterned progression o resistance for optimal training effect. The advantage of thi capability over previous systems is that the user can selec the overall pattern of exercise and the machine assume responsibility for changing the precise force level, th speed of movement, and the temporal sequence to achiev that pattern.

There are a wide range of treadmills, bikes, and exercis devices currently available that employ electrical contr features. These include such options as fat burn, up hi training, or cardiac modes. These types of equipmen change the speed or elevations with preprogramme actions that are determined at the manufacturing cente when the machines are made rather than by the perso exercising. The exerciser can select the programs pr sented on the control panel, but the response by th machine to the user is not at all related to the performanc but rather to the preset events stored in the memor Therefore, the person may be running "uphill" on th treadmill as determined by the imbedded system, bu not with responsive interaction between the equipmen and the individual moment by moment. This is a limitatio of most of the exercise equipment available in the marke place of the twenty-first century.

In the early 1980s, the first resistive training an rehabilitation device to employ computerized feedbac control of both resistance and motion during exerci was introduced to overcome the lack of machine–huma interactivity (55). For the first time, a machine dynamical adapted to the activity being performed rather than t traditional approach of modifying the activity to conform the limitations of the machine. Biomechanical results pr viously calculated could be used to program the actu patterns of motion for training or rehabilitation. The equi ment utilizes a passive hydraulic resistance mechanis operating in a feedback-controlled mode under control the system's computer.

A simplified functional description of this mechanisr the Ariel Computerized Exercise System, and its operatic is described. A hydraulic cylinder is attached to an exerci bar through a mechanical linkage. As the bar is moved, t piston in the hydraulic cylinder moves which pushes from one side of the cylinder, through a valve, and into t other side of the cylinder. When the valve is fully op there is no resistance to the movement of oil and, thus, resistance in the movement of the bar. As the valve closed, it becomes harder to push the oil from one side of t cylinder to the other and, thus, harder to move the ba When the valve is fully closed, oil cannot flow and the b will not move. In addition to the cylinder, the resistan mechanism contains sensors to measure the appli force on the bar and the motion of the bar. To descri

the operation of the computerized feedback loop, assume the valve is at some intermediate position and the bar is being moved at some velocity with some level of resistance. If the computer senses that the bar velocity is too high or that bar resistance is too low, it will close the valve by a small amount and then check the velocity and resistance values again. If the values are incorrect, it will continue to regulate the opening of the valve and continually check the results until the desired velocity or resistance is achieved. Similar computer assessments and valve adjustments are made for every exercise. Thus, an interactive feedback loop between the computer and the valve enable the user to exercise at the desired velocity or resistance. The feedback cycle occurs hundreds of times a second so that the user experiences no perceptible variations from the desired parameters of exercise.

There are a number of advantages in a computerized feedback controlled resistance mechanism over devices that employ weights, springs, motors, or pumps. One significant advantage is safety. The passive hydraulic mechanism provides resistance only when the user pushes or pulls against it. The user may stop exercising at any time and the exercise bar will remain motionless. Another advantage is that of bidirectional exercise. The hydraulic mechanism can provide resistance with the bar moving in each direction, whereas weights and springs provide resistance in only one direction. Opposing muscle groups can be trained in a single exercise. Two additional problems associated with weight training, noise and inertia, are also eliminated because the hydraulic mechanism is virtually silent and full resistance can be maintained at all speeds. Figure 9 illustrates an olympic training system utilized by the olympic athletes.

The Ariel Computerized Exercise System allows the user to set a pattern of continuously varying velocity or resistance. The pattern can be based on direct measurements of that individual's motion derived from the biomechanical analysis or can be designed or created by the user with a goal of training or rehabilitation. During exercise, the computer uses the pattern to adjust bar velocity or bar resistance as the subject moves through the full range of motion. In this manner, the motion parameters of almost any activity can be closely duplicated by the exercise system allowing training or rehabilitation using the same pattern as the activity itself.

The software consists of two levels. One level of software is invisible to the individual using the equipment since it controls the hardware components. The second level of software allows interaction between the user and the computer. The computer programs necessary to provide the real-time feedback control, the data program and storage, and the additional performance manipulations are extensive. The software provides computer interaction with the individual operator by automatically presenting a menu of options when the system is activated. Selection of the diagnostics option allows several parameters about that person to be evaluated and stored if desired. Some of the diagnostic parameters available include range of motion, maximum force, and maximum speed that the individual can move the bar for the specific activity selected. The maximum force and maximum speed data

Figure 9. Olympic training on the computerized exercise system.

can be determined at each discrete point in the range of movement as well as the average across the entire range. The diagnostic data can be used solely as isolated pre- and post-test measurements. However, the data can also be stored within the person's profile so that subsequent actions and tests performed on the equipment can be customized to adjust to that specific individual's characteristics.

The controlled velocity option permits the individual to control the speed of bar movement. The pattern of the velocity can be determined by the person using the equipment and these choices of velocity patterns include: (*1*) isokinetic, which provides a constant speed throughout the range of motion; (*2*) variable speed, in which the speed at the beginning of the motion and the speed at the end of the stroke are different with the computer regulating a smooth transition between the two values; and (*3*) programmed speed, which allows the user to specify a unique velocity pattern throughout the range of movement. For each of the choices, determination of the initial and final velocities is at the discretion of the individual through an interactive menu. The number of repetitions to be performed can be indicated by the person. Also, it is possible to designate different patterns of velocity for each direction of bar movement.

The controlled resistance option enables the person to control the resistance or amount of force required to move the bar. The alternatives include (*1*) isotonic, which provides a constant amount of force for the individual to overcome in order to move the bar; (*2*) variable resistance, in which the force at the beginning of the motion and the force at the end of the movement are different with the computer regulating a smooth transition between the two values; (*3*) programmed resistance, which permits the individual to specify a unique force pattern through-out the range of movement. An interactive menu enables the person to indicate the precise initial and final values, the number of repetitions to be used, and each direction of bar motion for the three choices. The controlled work option allows the individual to determine the amount of work, in Newton/meters or joules, to be performed rather than the number of repetitions. In addition, the person can choose either velocity or resistance as the method for controlling the bar movement. As with the previous options, bidirectional control is possible. The data storage capability is useful in the design of research protocols. The software allows an investigator to program a specific series of exercises and the precise manner in which they are to be performed, for example, number of repetitions and amount of work, so that the user need only select their name from the graphic menu and the computer will then guide the procedures. Data gathered can be stored for subsequent analysis. The equipment is fully operational for all options irrespective of whether the data storage option is activated.

Numerous features further enhance the application of this advanced fitness technology. Individual exercise programs can be created and saved on the computer, a CD, an internet file, or a USB disk. Users can perform their individual program at any time merely by loading it from any of the memory options used. Measurements of exercise results can be automatically saved and progress monitored by comparing current performance levels to previous ones. Performance can be measured in terms of strength, speed, power, repetitions, quantity of work, endurance and fatigue. Comparison of these quantities can be made for flexors versus extensors, right limb versus left limb, as well as between different dates and different individuals. Visual and audio feedback are provided during exercise to ensure that the subject is training in the proper manner and to provide motivation for optimal performance. Accuracy of measurement is essential and it is deemed as one of the most important considerations in the software. Calibration of the equipment is performed dynamically and is a unique feature that the computerization and the feedback system allow. Calibration is performed using weights with known values and the procedure can be performed for both up and down directions. This type of calibration is unique since the accuracy of the device can be ascertained throughout the range of motion.

FUTURE DEVELOPMENTS

As discussed previously, a large diagnostic and/or exercise system exists, but sheer bulk precludes its convenient use at home or in small spaces. One future goal is to develop

Figure 10. Motion analysis in space.

a computerized, feedback-controlled, portable, ba powered, hydraulic musculoskeletal exercise asses and training equipment based on the currently ava full-sized system. The device will be portable, compac operate at low voltage. Although physical fitness and health have become increasingly more important t American public, no compact, affordable, accurate either for measurement or conditioning human streng performance exists. This deficit hinders both Ame ability to provide convenient, affordable, and acc diagnostic and exercise capabilities for hospital or h bound patients, children or elderly, to adequately pe within small-spaced military areas, as would be fou submarines, or in NASA shuttle projects to explor frontiers of space. Figure 10 illustrates an astronaut ning on a computerized treadmill in a zero gravity e onment.

The frame will be compact and light-weight with a get weight of < 10 kg. This is an ambitious design goal will require frame materials to have maximum stre weight ratios and the structure must be engineered attention directed toward compactness, storage size, both ease and versatility of operation. The design smaller and lighter hydraulic valve, pack, and cyli assembly is envisioned. Software can be tailored to sp applications such as for the very young or the aged, sp orthopedic and/or disease training, or other applicati

Another future development will be the ability to d load programs through the Internet. For example, patient could have one of the small exercise devices at h His/her doctor can prescribe certain diagnostic activ and exercise regiments and transmit them via the Inte The individual can perform the exercises at home and submit the results to the doctor electronically. Biomech cal quantification of performances will become avail electronically by downloading the software and execu the procedures on the individual's personal comp Parents will be able to assist their child's athletic growth performances, doctors or physical therapists can compare normal gait with their patient's, and many other uses which may not be apparent at this time. The Internet can also function as a conduit between a research site and a remote location. Consider a hypothetical example of the National Institute of Health conducting a study on the effects of exercise on various medical, chemical, neural, and biomechanical factors for a large number of subjects around the world. The exercise equipment could be linked directly with Internet sources; the other data could be collected, and sent to the appropriate participating institutes. Findings from each location could then be transmitted to the main data collection site for integration.

CONCLUSION

National and international attitudes and policies focused on improving the health of children, workers, and the elderly must be directed towards good nutrition and improving lifestyles. It is made abundantly clean in print and televised media, that obesity has become a severe threat to the health and well being of Americans. That this problem is or will become an international epidemic may depend on the manner in which it is addressed. Exercise is no substitute for poor lifestyle practices, such as excessive alcohol consumption, smoking, overeating, and poor dietary practices. Attention must be directed to the importance of creative movements, posture, perceptual motor stimulation, body awareness, body image, and coordination. However, the importance of physical activity is too valuable to be limited to the young and healthy. Exercise, sports, and other physical activities must include all ages without regard to their frailty or disabilities.

The laws of nature rule the human body. Chemical and biological laws affect food metabolism, neurological transmissions within the nervous system and the target organs, hormonal influences, and all other growth, maintenance, and performance activities. Mechanical influences occur at the joints according to the same laws that return the pole vaulter to earth. Food, water, air, and environmental factors interact with work and societal demands. Human life is an interplay of external and internal processes and energy and, according to the second law of thermodynamics, the system will move toward increased disorder over time (56).

In terms of the universe, the first law of thermodynamics states that the total energy of the universe is constant. The second law states that the total entropy of the universe is increasing. The measure of a system's disorder is referred to as entropy and Eddington said, Whenever you conceive of a new theory of unusually attractiveness, but it does not in some way conform to the second law, then that theory is most certainly wrong (57). Everyone inevitably grows older. Delaying the process of disorder by keeping the subsystems of the organism at a low level of entropy does not flaunt the second law, but rather exploits it.

Science and technology have afforded us the ability to quantify movement so that humans can use their bodies more efficiently. Normal movement of small children can be reflected in improved diapers that do not alter their gait.

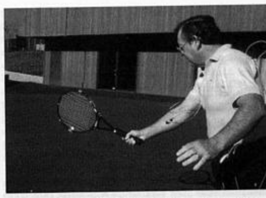

Figure 11. The EMG analysis of a tennis stroke.

Assessment of workplace activities can identify movements that are biomechanically inappropriate for healthy workers. Changing the design of the work bench, providing variable height stools for the conveyor belt operators, and evaluating the job requirements to assist in matching the employee to the work, improved wheelchair design, and adaptations in housing for the elderly are just a few examples of how biomechanical analysis can be applied. Figure 11 shows how athletic performance and equipment are assessed scientifically.

Not only has scientific and technological means provided quantitative assessment abilities, but has also allowed the development of improved means for exercising. Exercise equipment has become so sophisticated that it is appropriate for all ages. The youngest and the oldest can benefit from improved muscular health; the weakest and the strongest can always improve or, at the very least, sustain, healthy muscles; and those with compromised health or bodily functions should enjoy the opportunities to improve their musculature.

Logically, consumption of proper food, sleeping or resting sufficiently, and engaging in an appropriately amount of intense physical activity should keep the tissues and organs functioning maximally. To extend and improve the length and the quality of life depends on an increased awareness of human anatomy, biology, and physiology with continuous research efforts in these and other areas which impact human life. The aging process cannot be overcome, but it should be possible to negate many of the debilitating aspects of it. The Declaration of the United States of America is the only document of any country in history which includes the statement of "pursuit of happiness" and this concept should apply to the health and quality of life for all peoples, regardless of location, and at every age: from infancy to the twilight years.

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See also EXERCISE STRESS TESTING; HUMAN SPINE, BIOMECHANICS OF; JOINTS, BIOMECHANICS OF; LOCOMOTION MEASUREMENT, HUMAN; REHABILITATION AND MUSCLE TESTING.

BIOMECHANICS OF JOINTS. See JOINTS, BIOMECHANICS OF.

BIOMECHANICS OF SCOLIOSIS. See SCOLIOSIS, BIOMECHANICS OF.

BIOMECHANICS OF SKIN. See SKIN, BIOMECHANICS OF.

BIOMECHANICS OF THE HUMAN SPINE. See HUMAN SPINE, BIOMECHANICS OF.

BIOMECHANICS OF TOOTH AND JAW. See TOOTH AND JAW, BIOMECHANICS OF.

BIOMEDICAL ENGINEERING EDUCATION

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INTRODUCTION

Biomedical engineering is that interdisciplinary field of study combining engineering with life sciences and medicine. It is a relatively new field of study that has only recently experienced sufficient maturity to enable it to establish its own identity. Often, this field will be described using the term bioengineering. In 1997, the Bioengineering Definition Committee of the National Institutes of Health released the following definition of the field (1): "Bioengineering integrates physical, chemical, mathematical, and computational sciences and engineering principles to study biology, medicine, behavior, and health. It advances fundamental concepts; creates knowledge from the molecular to the organ systems level; and develops innovative biologics, materials, processes, implants, devices and informatics approaches for the prevention, diagnosis, and treatment of disease, for patient rehabilitation, and for improving health."

While many use biomedical engineering and bioengineering interchangeably, it is generally accepted today that bioengineering is a broader field that combines engineering with life sciences, but is not necessarily restricted to just medical applications.

The Biomedical Engineering Society further elaborated on the definition of biomedical engineering as part of a guide on careers in the field. In it is stated (2): "A Biomedical Engineer uses traditional engineering expertise to analyze and solve problems in biology and medicine, providing an overall enhancement of health care. Students choose the biomedical engineering field to be of service to people, to partake of the excitement of working with living systems, and to apply advanced technology to the complex problems of medical care. The biomedical engineer works with other health care professionals including physicians, nurses, therapists and technicians. Biomedical engineers may be called upon in a wide range of capacities: to design instruments, devices, and software, to bring together knowledge from many technical sources to develop new procedures, or to conduct research needed to solve clinical problems."

Educational programs in the field of biomedical engineering had their origins in a handful of specialized graduate training programs in the 1950s focusing primarily on diagnostic and therapeutic devices and instrumentation. By 2004, there were undergraduate and graduate programs in biomedical engineering at ~100 universities in the United States. The diversity in the content of undergraduate educational programs that was commonplace in its early years is gradually diminishing as the field has matured. While the current undergraduate programs still maintain their own unique identity, there has been a steady movement toward the definition of a core curriculum in the field.

The purpose of this article is to give the reader some historical perspective on the origins of educational programs in the field, the challenges associated with preparing bachelor-level graduates for careers in the field, and the current state-of-the-art in undergraduate biomedical engineering curriculums.

HISTORY

The first steps toward establishing biomedical engineering as a discipline occurred in the 1950s as several formalized training programs were created. Their establishment was significantly aided by the National Institutes of Health