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High Tech in Sports

How Biomechanical Research Can Optimize Athletic Performance

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High Tech in Sports: The Role of Computers in Sports Analysis

This article by Dr. Gideon Ariel, President of the Coto Research Center and Chairman of Computer Sciences/Biomechanics at the U.S. Olympic Committee, discusses the indispensable role of computers in sports analysis. The computer's ability to follow instructions, remember everything, and calculate to the thousandth of a second makes it a perfect tool for analyzing sports techniques.

The article highlights how the computer surpasses the limits of human observation and intuition, but emphasizes that human judgment remains crucial in decision-making. The computer is seen as a tool to aid coaches in achieving desired results.

The article also discusses the success of East Germany in international competition, attributing it to the effective use of national resources, including the use of science in the development of national training institutes. The United States has learned from this approach, blending resources such as talented young athletes, dedicated coaches, brainpower, and wealth.

The article further discusses the use of high-speed movie cameras and computers in analyzing body movements in real-time. The advent of computers has also allowed the design of intelligent systems for training, enabling the exercise modality to adjust to the training method selected by the individual user.

The article concludes by stating that the union of computerization and exercise equipment is the future trend, representing a new era in physical fitness, physical therapy, and athletic training.

This article discusses the complex biomechanics of the human body, particularly in relation to athletic performance. It explains how the central nervous system controls muscle contraction and movement, comparing the body to a symphony orchestra with the central nervous system as the conductor. The article also delves into the concept of biofeedback, explaining how the brain processes and responds to sensory information. It further explores the role of the brain as a control system, highlighting its importance in athletic performance. The article also touches on the use of drugs in sports, arguing that high technology and modern training methods can replace the need for performance-enhancing substances.

This article discusses the controversial use of anabolic steroids in sports, particularly in the Olympics. It highlights a study where subjects showed greater improvement in their muscular force during periods of steroid use. The article criticizes the Olympic Committee's approach to the issue and discusses the widespread use of steroids among athletes worldwide. It also mentions a conference held in Philadelphia where participants agreed that many athletes were taking steroids regularly, often in conjunction with other drugs. The article suggests that technology and innovation could provide a solution to the drug problem in sports, as steroids cannot contribute to the development of speed, only muscular bulk. The article also discusses the use of technology in training and understanding opponents in sports, using the example of the U.S. Olympic Women's Volleyball Team.

The article discusses the relationship between anatomy and physiology, emphasizing the role of energy in physiological processes. It highlights the importance of ATP in muscle function and the difference between aerobic and anaerobic capacity. The article also explores the role of the brain in controlling behavior and the complexity of the nervous system. It delves into the different types of muscle fibers, their characteristics, and their impact on athletic performance. The article further discusses the three major components of muscular contraction and the role of elasticity in athletic performance. It also touches on the laws of mechanics and their application in sports, using examples from discus throwing and hurdling. The article concludes by emphasizing the shift from viewing athletics as an art to understanding it as a science.

The article discusses the importance of understanding the mechanics of movement in sports. It emphasizes that actions requiring near maximum force, such as throwing a baseball or high-jumping, rely on efficient acceleration and deceleration of the body's link system. The goal is to move mass quickly and smoothly, transmitting force from joint to joint. Unlike psychology or physiology, the mechanics of athletics observe a universal law. The author suggests that future coaches must understand these laws and how to apply them to their sport. The coach who can best apply these principles will have a competitive advantage. The author plans to discuss the intersection of biology and mechanics in sports in the next article.

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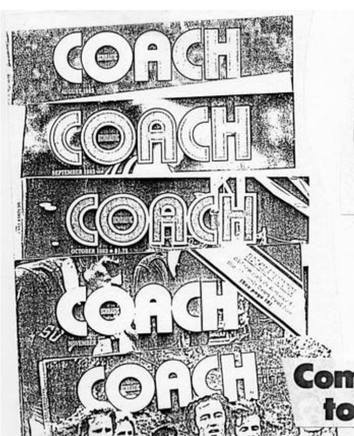

HIGH TECH IN SPORTS

Complete Application to Sports Analysis

How Biomechanical Research Can Optimize Athletic Performance

By DR. GIDEON ARIEL
President, Coto Research Center
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THE computer has become indispensable in finance, industry, and government. Because it can follow instructions *exactly*, remember *everything*, and *calculate* to the thousandth of a second, it can quickly and precisely analyze problems that would ordinarily require enormous amounts of time and energy to solve.

Our sport scientists know a good thing when they see it, and it didn't take them long to "discover" the electronic wizard. In competitive athletics, everyone is always looking for perfection—or at least an edge—and the computer lends itself perfectly to the analysis of technique. It is the one device that surpasses the limits of what the human eye can see and the intuition deduce.

Human judgment is still critically important, however. As in the world of commerce, where decisions are based upon an executive's experience and interpretive ability, the coach must be the ultimate decision-maker in training. The computer must be regarded as a *tool* in the achievement of the desired end.

The success of East Germany in international competition can be considered a triumph for national organization—for what can be accomplished by the pooling of national resources.

The East Germans made victory in international competition a top priority. They sought out their best young talent for intensive training in the finest of facilities, and recruited science in the development of national training institutes.

The United States has learned something from East Germany. The new U.S. Olympic Training Centers attest to the principle that winning requires more than the dedication of individual athletes, that it also requires a national effort.

The United States has always had the resources in its talented young athletes, dedicated coaches, brainpower, and wealth. All that it needed was to blend them.

In the past, athletic achievement depended mainly upon individual talent. Genetically superior athletes who successfully interacted with the available facilities, equipment, and personnel dominated the list of world-record holders.

The constant improvement in equipment and techniques has complemented this raw talent. However, the advent of new measuring tools and scientific knowledge has added a new dimension, and the coach must learn to use such technology in optimizing the function of the body in each event.

Since the body abides by the same physical laws as all other earthly objects, its performance must be governed by the laws of motion.

Take throwing, running, and jumping. It's impossible to throw the shot 20 meters without attaining specific values in shot velocity and angle of release. These values cannot be altered for different athletes. Each particular shot velocity has just one optimal angle.

For a long jumper to leap 8 meters, he must produce certain forces on the ground to propel his body with a specific reaction force at a particular angle. This force is unique; it is impossible to cover the same distance with only a fraction of this force, as gravitational pull acts uniformly, regardless of the jumper.

The concept emphasized here is that all bodies, athletes, implements, or machines, are affected by and must adhere to the laws of motion.

A number of scientists have long recognized these facts of force and motion and their relationship to humans. But they lacked the kind of equipment that could measure and analyze the motions and forces involved, the kinetics, and this impeded further research.

The computer provided the initial resource.

Another important contributor was the National Aeronautical and Space Agency, which made detailed measurements of the human body. These measurements included the relative mass for body segments such as arms, legs, or hands when given the overall height and weight of the individual.

Another critical element was the high-speed movie camera that provided sequences of the body in real time motion. Knowing the speed with which film travels through the camera, the scientist and the coach can determine the velocity and acceleration of the body segments, using its joints as points of reference.

If, for example, the shutter speed is 200 frames per second, one can determine the location of the right knee at the start of a sprint and then compare it with the position of the right knee in the 20th frame, thereby learning how far the right knee has moved in one tenth of a second.

The data can be further utilized to ascertain velocities, accelerations and, with some additional information, even the forces involved.

A computer can rapidly store information, retrieve it, and perform numerous computations. Without such calculating abilities, an architect, for example, would be in the impossible position of trying to build a cathedral one stone at a time with the blueprints only in his head.

Before a computer can perform its job, whether it is to build a house, guide a robot, print a check, or retrieve a space vehicle, it needs a program. That is, it needs a sequence of instructions which tell it how and what to do.

The beauty of a computer (and its program) is that it can play the great coaching game of "what if". You can ask, "What if I hold the shot down here and then whirl in this fashion?" The computer will tell you how far the shot would go, applying the amount of force developed in previous analysis.

The computer, then, helps the coach write equations and construct models which will produce optimal performance.

The dramatic effect of computer application to sports analysis first struck me when I began analyzing human motion. I had no direct way of inputting my motion-picture observations into the computer. I had to manually outline each frame of the film sequence on a sheet of paper fixed to a wall. Then, for each frame, I'd have to measure the angles made by the segments as well as their lengths.

All of this had to be done with rulers and protractors, and the information then recorded on computer keypunch cards. If I accidentally dropped the cards, it was impossible to rearrange them into the proper sequence and the information would have to be redone.

This method was too laborious for any large scale analysis. In 1971, I learned that the medical school at Dartmouth College employed a device called the sonic digitizer to measure angles required for scanning laser beams in the brain. Since its principles fit my needs, I adapted it to my work.

With the digitizer, I could project the frames from a film onto a glass screen. With the sonic pen, I needed only to touch the points of reference (such as the body joints or the outline of a hockey puck) on the screen and the information would instantly be recorded in the computer memory. Angles and lengths could all be swiftly measured.

Since that time, high technology has allowed us to adapt a newer method that uses electronic scanners. These capture the motion in digital forms which represent gray scales for subsequent analyses, eliminating the necessity of film and manual digitizing.

Along with the analyses based upon films taken during actual events, we have also developed sensitive force platform applications. These allow controlled laboratory testing of forces, such as when an object like the human foot strikes the plate during a sprint. The plate is capable of recording four different kinds of forces: (1) vertical, (2) horizontal, (3) sideways or lateral, and (4) moment or torque.

High technology is also being utilized in constructing computerized exercise equipment. This sophisticated equipment permits the athlete to train more efficiently and also provides a scientific tool with which to research factors contributing to optimal training.

This new technology will be discussed next month.

SCHOLASTIC COACH SEPT. 198?

Biotechnology in Training

The emergence of the computer is comparable to the invention of writing.

HAVING discussed the effect of high technology on modern training last month, I would now like to explain how such technology can be applied to the training of athletes.

Biotechnology utilizes computer science, physiology, biocybernetics, biomechanics, and neuroscience in the field of sports science. It allows the coach, trainer, physical therapist, and physician to utilize the best instrumentation and tools, such as computers and artificial intelligence, to improve human performance.

These new machines provide means for testing hypotheses, examining theories, playing "what if" games, and reshaping human thought at a level of complexity that no other intellectual tool has been able to provide for the athlete.

The production of intelligent machines is comparable to the invention of the printing press, and has the potential for making an even greater impact on the life of the mind. Mathematician Seymour Papert of MIT says that "The effect of the computer on learning and thinking is comparable to that of the invention of writing".

High technology allows humans to overcome such biological limits as calculating, executing, detecting, and remembering. It also can assist in defining the world around and within our bodies. For the first time, we have a technological potential for projecting the human mind and discovering how it works and how it effects performance.

Movement and Performance

The common denominator for all athletic performance is movement. The elementary requirements of movement are, first, muscle and, second, a signaling system that makes muscles contract in an orderly manner.

Not all muscles work in the same way. Compare, for example, the muscles of the human eye with those of the arm. Eye muscles must operate with great speed and precision to quickly orient the eyeball and to focus on an object.

The fine control needed in eye movement calls for a high innervation ratio of the number of neurons with axons terminating on the outer membrane of muscle cells to the number of cells in the muscle. For the eye muscles, the innervation ratio is about one to three, which means that the axon terminals of a single motor neuron release their chemical transmitter to no more than three individual muscle cells.

Muscle Motor Units

In contrast to this high innervation ratio, the axon terminals of a single motor neuron for a limb of muscle, such as a biceps, may deliver their chemical transmitter to hundreds of muscle fibers. The muscle may, therefore, have a low ratio of one to many hundreds.

As a result, the output of the motor unit for a limb muscle is correspondingly coarse, particularly when compared with the fine precision needed with the control of the eye.

Muscle motor units also differ in their susceptibility to fatigue. At one extreme are slow-twitch motor units which have great resistance to fatigue. Such units can remain active for long periods, but they generate relatively little muscle tension.

At the opposite extreme are fast-twitch motor units which can generate a large peak muscle tension but fatigue rapidly. Within a single human muscle, the fibers of slow and fast motor units are intermixed.

What is the importance of these contrasting motor unit properties to the organization of movement? Consider how the motor units of a muscle are sequentially recruited in the course of a movement. In general, muscle tension is regulated in two ways: (1) through control of the number of motor units recruited to act, and (2) through control of the firing frequency of the recruited units.

Slow-twitch units, which are resistant to fatigue, can generate little tension and are the first to be recruited. Fast-twitch units, which generate large peak tensions but are quickly fatigued, are the last motor units to be recruited.

Athletic movement is a series of individual actions that begin with electro-chemical processes infinitely swifter and more complicated than any known control system. For instance, a simple movement, such as crooking a finger or raising an eyebrow, involves a complex of neuromuscular happenings that cannot be duplicated by artificial means. The best man-made robot still moves in jerks and stops when compared to the subtle, fluid motions of a human.

Enter the Computer

For us to train this complex system, it is necessary to rely on sophisticated training concepts and equipment. The advent of computers makes it possible to design an intelligent system which will be able to "feel" and "understand" the control mechanism of the athlete and, therefore, adjust and monitor the training effect to allow optimal results.

Unfortunately, many professionals have been afraid of the computer, since it was considered to be very complicated. It is only recently, as our professionals began seeing their children operate these "marvels" so easily, that they have begun paying more attention to these marvelous devices.

Only a few years ago, the people who used computers were highly trained specialists who spoke a jargon that no one else understand. They used computers beyond the financial means of the average person. Consequently, the initial computerization of the industrial processes was a behind-the-scenes revolution that remained largely invisible to the public.

Since these earlier days, both the cost and the size of the computer have been reduced, making it possible for us to adapt its intelligence to resistive strength training.

One of the most important characteristics that must be incorporated into training devices is the concept of feedback. Without this ability, the devices would be useless. Imagine a potter who could not feel the clay, or a steam shovel that could not distinguish between dirt and department-store windows.

In other words, strength training devices are really effective only if they can recognize changes. And to recognize changes, the training device, because of its artificial intelligence, needs a computer.

No other training modalities have had computers, and the athlete has had to determine the amount of resistance and the number of repetitions desired in order to increase the strength of the muscle.

The neuromuscular requirements of the training session have also been ignored. The user has had to make the choices because the exercise modalities were inherently incapable of any intellectual participation.

The advent of computers has made it possible to design exercise equipment with artificial intelligence, enabling the exercise modality to adjust to the training method selected by the individual user.

The union of computerization and exercise equipment is the trend of the future. It is the result of the application of many unique features and mechanisms to the long-established fields of resistive exercise training, rehabilitation, and physical fitness.

The underlying principle behind these innovations is that of a computer-controlled feedback or servomechanism which is able to maintain any desired pattern of force and motion throughout the range of each exercise, regardless of the magnitude or rate of force applied by the person exercising.

Trend of the Future

One of the most significant advantages of a computer-controlled exercise mechanism is the introduction of a stored computer program to the feedback loop. The computer, and its associated collection of unique programs, allows the feedback-controlled resistance to vary not only with the measured parameters of force and displacement, but to modify the feedback loop while the exercise is in progress.

This modification can, therefore, reflect changes in the pattern of exercise over time. The unique program selection can effect such changes in order to achieve a sequential or patterned progression of resistance for optimum training effect.

The advantage of this capability is that the user can select the overall pattern of exercise while the machine assumes responsibility for choosing the precise force level, speed of movement, and temporal sequence to achieve that pattern.

Consider the following typical examples of exercises which can be performed on this intelligence exercise machine. A user wishes to select a resistance (weight, in classical terms) starting at half his body weight, and to have that resistance increased by 10% in each successive repetition, until the user reaches a "sticking point" and cannot continue.

With a classical weight machine, he would have to select weights equal to half his body weight and then stop between repetitions to change weights. The training effect of the exercise also would be considerably affected because, while he stopped to change weights, his muscles "recover".

With the computerized machine, the person's weight would automatically be determined. Then the computer would select the pattern of increasing force, starting at precisely half his body weight, and increasing the resistance by just 10% after each repetition until it detected that the user could no longer move the bar.

At this point, it would report the final force level, the number of repetitions, and, if desired, the progress the user had made since the last exercise session.

The computer controlled resistive exercise system represents a new era in physical fitness, physical therapy, and athletic training. For the first time, the coach has a training device which can extend his own ability to design a program and allow constant evaluation for enhanced progress.

One should remember that the computer's artificial intelligence is totally dependent on the decisions of the coach and only then can the program be optimized.

Performance starts in the nervous system and propagates outward

MUSCULAR & NEURAL CONTROL IN SPORT

By DR. GIDEON ARIEL
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WHEN athletes mention their physical goals, they're usually content to say that they would like to do their best—incorporate their maximum speed, strength, endurance, and skill into the performance.

Athletics can be likened to a spectrum.

On one end are the explosive events such as throwing, jumping, sprinting, and weight-lifting.

On the other end are the esthetic events such as gymnastics, diving, and figure-skating, where success depends upon the ability to create movements pleasing to the judges.

In the middle of the spectrum are the endurance events, in which the athlete attempts to maintain muscular contractions at submaximal intensity levels for long periods of time.

In between these extremes are the events which require the athlete to repeatedly shoot or hit a target with a high level of consistency and accuracy.

Team sports incorporate many overlapping characteristics. The football player, for example, needs explosiveness, endurance, and accuracy.

The common denominator for all athletic activity is movement, the elementary requirements of which are the muscles and a signaling system that makes the muscles contract in an orderly fashion. (For an analysis of movement, see my article in last month's Scholastic Coach.)

Athletic performance consists of many combinations of electro-chemical processes. The science which measures the resulting actions is called "biomechanics". The "bio" part perhaps more properly falls within the area of biology known as physiology—which deals with the functioning of living organisms or their parts.

The building frames of the body are the bones, which are joined by connective tissue known as ligaments and tendons. Bones have no power to move, however. Like the frame of an automobile, they provide the basic structure upon which the body, or the engine which supplies the power to move, rests.

It is the 600 muscles of the body, accounting for about 40% of the total weight, which do the work. And it is the relationship of levers, fulcrums, muscular "power", and all of the inertial forces that constitute the "mechanical" portion of "biomechanics."

Muscles are made to contract by signals from the central nervous system. But the muscles do not respond unless they receive the appropriate simulation—and they require a given signal every time they are expected to perform.

Muscular contraction causes the joint angles to change, according to the coordination of the varying amounts of tension produced in the individual fibers. Individual cadres of these muscles surround the various joints and control the segments so that the body's actions are like a mechanical link system moved by reciprocating engines.

This intricate arrangement of bones, muscles, and neural control accounts for all muscular activities.

Performance starts in the nervous system (or in stimuli that cause activity in the nervous system) and propagates outward from there according to physical laws of cause and effect.

N.A. Bernstein in 1935 compared the workings of this human machine to a symphony orchestra:

> *Each instrument plays its individual score. So, in the act of walking, each joint reproduces its own curve of movements and each center of gravity its sequence of accelerations; each muscle produces its melody of efforts, full with regularly changing but stable details, and in like manner the whole of this ensemble acts in unison with a single and complete rhythm, fusing the whole enormous complexity into a clear and harmonic simplicity. The consolidator and manager of the complex entity—the conductor and at the same time composer of the analyzed score—is, of course, the central nervous system.*

In the 1700's, Galvanni saw that frog muscles contracted when electrically stimulated. He deduced that electrical current must be involved in the normal muscle contraction process.

While chemical-mechanical interaction operates muscles, any understanding of biofeedback requires an appreciation of biocybernetics, which is the study of control and communication in humans.

The central nervous system, headquartered in the brain, is an incredible hive of activity. Ten billion cells engage in an electro-chemical operation that, in conjunction with other body parts, permits us to see, hear, reason, imagine, create, love, hate, move, and be aware of exactly which process we are involved in through the capacity to incorporate feedback into the operation.

The building block of the system is a specialized nerve cell known as a neuron. Bundles of neurons are organized into larger entities called nerves. These serve as gateways to speed a constant stream of information from eyes, ears, nose, and other areas to the neurons of the brain, which evaluate the data in light of evolution and individual experience.

Other kinds of nerves, with special cells known as receptors, monitor such stimuli as pain, cold, touch, pressure, and even blood and body chemistry. The neurons of the brain constantly combine the data of the present with the coded information stored in the brain. They also barrage another set of special neurons, known as motor neurons, with signals.

These motor neurons within the brain and at the target sites control the movement of our muscles and the secretions of our glands. They not only trigger the chemico-mechanical process of working muscles but also try to govern the action.

BRAIN MECHANISMS

For the body to regulate movement in athletic performance, it must have information about what it controls. A servomechanism must be introduced to accomplish this.

Many current concepts of the brain mechanisms of movement have evolved from the work of the British physiologist, Sir Charles Sherrington, on the function of the motor neuron in certain reflexive forms of motor activity, such as athletic performance.

Sherrington's work (in the early 20th century) led to today's concept of the "triggered movement" based on a "central program" involving a spinal rhythm generator.

Many current investigations of the neurophysiology of locomotion are aimed at clarifying the interaction between what may be termed "central programs" from the brain and "sensory feedback" from outside the nervous system.

Sherrington introduced the term "proprioception" to describe the organism's detection of stimuli by the receptors.

There are two kinds of muscle proprioceptors. One senses elongation; the other, tension. The length receptors of muscles send fibers into the spinal cord to form synapses on motor neurons that terminate on the same muscles.

Hence, any increased length receptor activity that results from muscle elongation activates the motor neurons of the elongated muscle. This, in turn, gives rise to a muscular contraction that opposes elongation.

The tension receptors sense force rather than elongation. Their activation leads to the inhibition of the associated motor neurons. Thus, when an increase in muscle tension activates these receptors, their response acts on the associated motor neurons and gives rise to a reduction in force.

Though the brain is primarily associated with the process of thinking, it is first and foremost a control system.

Both the length receptors and the tension receptors may, therefore, be viewed as components of what an engineer would call a negative feedback control system. This particular system maintains its stability by resisting changes in muscle length and tension.

These control mechanisms in the muscles and tendons themselves are governed by higher level mechanisms in the brain. In fact, the control of movement relies on hierarchical control. The sensory information in the muscle itself processes local information and transmits net results to higher centers.

Feedback enters the hierarchy at every level. At the lowest levels, the feedback is unprocessed and, hence, is fast acting with a very short delay. At the higher levels, feedback data pass through more and more stages of an ascending, sensory-processing hierarchy.

Feedback thus closes a real-time control loop at each level in the hierarchy. The lower level loops are simple and fast acting. The higher level loops are more sophisticated and slower. The combination generates a lengthy sequence of behavior which is both goal-directed and appropriate to the environment.

Such behavior appears to be intentional or purposive. The top level input command is a goal, or task, which is successively partitioned into subgoals, or subtasks, at each stage of the control hierarchy until, at the lowest level, output signals drive the muscles and produce observable behavior.

HIERARCHAL CONTROL

The success or failure of any particular task, or goal-seeking action, depends on whether or not the higher level functions are capable of providing the correct information. This hierarchial control is necessary so as to direct the output to the lower level for successful performance despite perturbations and uncertainties in the environment.

Small perturbations can usually be corrected by low level feedback loops, as was described for the length and tension sensors. These involve relatively little sensory data processing and, hence, are fast acting.

Larger disturbances, due to changes in the environment or perhaps to execution of a difficult activity, may overwhelm the lower level feedback loops and require strategy changes at higher levels in order to maintain the system within the region of successful performance.

Thus, a highly skilled and well-practiced performer, such as a gymnast on a balance beam only four inches wide, can execute extremely difficult maneuvers with apparent ease.

Many such activities seem to be performed with a minimum of physical and mental effort. The performances are often described as "effortless" or "done without even thinking".

What is really meant is that the athlete's lower level corrections are so quick and precise that the performance does not deviate significantly from the ideal. There is never any need for higher level loops to make emergency changes in strategy.

On the other hand, a novice gymnast may have great difficulty in even executing a performance. He or she is continually forced to bring higher levels into play to prevent failure, and even the slightest deviation from the planned or desired motion will result in a loss of balance.

He or she works very hard, and often fails. Because the responses are late and often misdirected, the performance is erratic and rarely resembles the ideal.

Practice enables the athlete to perfect the mistimed functions and to create the capacity to reprogram the movement more efficiently.

The degree and precision of these corrections, and the method by which they are computed, determine the rate at which the learning process can produce an efficient and successful performance.

The control of muscular contraction in an athletic performance is very sophisticated and highly programmed. Consider, for example, the highly skilled matter of signing one's name.

Whenever Mr. Smith signs his name, it is consistent enough to be recognizable and different enough to prevent anyone else from accurately duplicating it. The individuality always remains.

This complex handwriting movement possesses a pre-programmed control mechanism. Optimum performance likewise depends on the control efficiency. It does not matter how strong the muscles are or how efficient the metabolism. The neural control of the muscles in executing the skill is the most important factor.

A CONTROL SYSTEM

Most people associate the brain primarily with the process of thinking. Yet research shows it to be first and foremost, a *control system*. Thought is *not* the primary purpose of the brain. It is, rather, an artifact that rises out of the complex computing mechanism required to generate and control extremely sophisticated behavior.

Sometimes, this ability to think causes inhibition in our control mechanism. Consider the athletes who fail to perform due to "mental" inhibition, or what we call "choking".

BIOFEEDBACK FUNCTIONS

The biofeedback machine in the body may be compared with the modern computer. However, the single computer element in the brain is the cell. Each cell acts as a computer, and there are 10 billion of them. The vast quantities of feedback information is analyzed and processed in innumerable computing centers—which detect patterns, compare incoming data with stored expectations, and evaluate the results.

One of the main differences between the brain and a computer is that the brain is capable of many computations in many different places simultaneously, whereas the computer executes sequential programs of instructions.

The biofeedback functions are executed in two basic ways. In the first, a signal is broken into many values which can be added to other numbers. This is the way a computer adds signals. It is called digital processing.

The other method is called analog, and the brain relies on this method for its fundamental computations. Analog computers perform operations by the addition of continuous signal values.

Each neuron in the brain is essentially an analog computer performing complex additions, integrations, differentiations, and nonlinear operations on input variables that can number from one to several hundred thousand.

The brain is a digital device only in that information is encoded for transmission from one neuron to another over long transmission lines, called axons, by pulse-frequency or pulse-phase modulation. When these pulse encoded-signals reach their destinations, they are reconverted into analog voltages from the computations which take place in the dendrites and cell bodies of the receiving neurons.

Success in a particular event, whether for explosive, endurance, or esthetic purposes, depends on the motor programming that initiates a proper biofeedback signal to the motor pool.

Individual muscle fibers make a muscle contract and relax in an elaborate synchronization. The arrangement permits them all to arrive at a peak of action simultaneously. But certain recruitment patterns characterize each event in a unique way.

The synchronization of muscle firing is critical for optimizing many performances. In the power events, such as discus throwing or high jumping, it is extremely important for the muscle actions to be simultaneously activated to optimize the force. The lack of synchronization in the power events results in lesser force and poorer performance.

On the other hand, in endurance events such as long-distance running or cross-country skiing, asynchronization is important since fewer fibers are needed to maintain the action, thus permitting alternating fibers to "rest".

It's true that some long-distance runners may "over-recruit" muscle fibers and, therefore, fatigue sooner—emphasizing the importance of technique in achieving optimal performance.

The question arises as to how the brain adapts to the specific activity requirements. The answer relies on the great number of approximations that must form the correct signal.

The brain achieves its incredible precision and reliability through redundancy and statistical techniques. Many axons carry feedback and feedforward information on the value of the same variable, each encoded slightly differently. The statistical summation of these many imprecise and noisy information channels produces the transmission of precise messages over long distances.

In a similar way, a multiplicity of neurons may compute roughly the same input variables. Clusters of such computing devices provide statistical precision and reliability orders of magnitude greater than that achievable by any single neuron.

The outputs of such clusters are transmitted and become inputs to other clusters, which perform additional analog computations.

Since the model of ideal performance consists of fantastic complexity, modern sports sciences rely on biofeedback to enable the coach and the athlete to achieve the maximum performance.

The two main disciplines needed to achieve these goals are biomechanics and computer sciences.

THE PHARMACEUTICAL ATHLETE: An Olympian Dilemma

What can we do about all the athletes on drugs?

By DR. GIDEON ARIEL / Chairman, Computer Sciences/Biomechanics, U.S. Olympic Committee

SCHOLASTIC COACH NOV. 1983

THE athletic world went into shock over the drug "scene" at the Pan American Games in Venezuela. The new drug-detecting devices created all kinds of embarrassment for both our athletes and for us as a nation.

We now definitely know: The widespread use of drugs has created a "chemical technology race in sports" with profound health, political, and ethical implications.

As a member of the U.S. Sports Medicine Committee, I am not surprised by these events. The committee has known for years that our athletes have been using steroids to enhance their strength.

At a recent meeting of the council of Sports Medicine, I challenged one of the physicians to reveal exactly how many athletes were on anabolic steroids. His answer was staggering: *Nearly 100% of our weight-event athletes were making extensive use of steroids.*

Role of anabolic steroids . . .

Questions: With all the technological advances in sport, (1) is drug use really necessary, and (2) can high technology replace them?

I believe that high technology *can* solve the problem, that modern methods of training *can* surpass the pharmaceutical approach.

The efficiency of performance depends upon many factors. Since all activities rely ultimately on the voluntary contraction of muscle tissue for driving force, such training is essential for the athlete, particularly for activities in which force is a dominant factor.

Many athletes, in their efforts to improve performance, have been supplementing their training regimens with an endless variety of ergogenic aids and drugs. The anabolic steroids are being used to accelerate the development of muscular force and body weight.

Until recently, the difficulty of detecting them in the urine or blood assured their continued use, despite their illegality. My experience indicates that the top medal winners in most of the recent Olympics have taken one or more anabolic agents.

As early as 1971, Jay Silvester, former world record holder in the discus, was quoted as saying:

There's no question, no question at all, that anabolic steroids have an effect on performance. I don't feel they are ethically defensible, but there doesn't seem to be any way to legislate against them or to police the athletes. I've taken the drugs in the past. In fact I was given them in 1964—when I didn't even know what they were—by an Olympic team physician.

Ken Patera, an American competing in the 1970 world weightlifting championships, told the N.Y. Times Magazine (October 17, 1971) that lifters have been using steroids regularly for years.

After winning a gold medal at the Pan American Games, Patera told about an encounter with the Russian champion, Alexeyev, at the Olympics in Munich:

Last year the only difference between me and him was that I couldn't afford his drug bill. Now I can. When I hit Munich next year, I'll weigh in at about 340 pounds. Then we'll see which is better—his steroids or mine.

Despite official censorship, athletes have continued to use anabolic steroids, purportedly to stimulate muscle growth and increase muscular force. Although scientific data on anabolic agents are sparse, there is sufficient clinical evidence that such drugs can stimulate muscle hypertrophy and muscular force.

Remember, much of the evidence is *clinical* in nature; quality research with healthy human subjects is lacking.

Physiological bases for steroids . . .

In order to understand the problems associated with steroids, it is necessary to study several of the physiological bases for these substances. There are two major systems normally present in the blood.

They usually are bound to specific carrier proteins while being transported in the blood. They are believed to be catalytic in effect, since the magnitude of the hormone-mediated response is out of proportion to the amount of hormone required to evoke the response.

Once the hormones have accomplished their missions, their production is diminished or inhibited by the hormones they have produced or by other neuro-hormonal mechanisms. In this way, the endocrine balance is normally maintained.

The steroid hormones are very specific in their structure and physiological actions. The natural anabolic steroids are secreted by the testes and the adrenals. The two main functions of the testes are hormonal and reproductive. Testosterone can be considered the single significant factor responsible for the male hormonal effects caused by the testes.

Psychological effect on elite athletes . . .

In the early 1970's, the effect of anabolic steroids on elite athletes was of special interest to me, and I conducted several experiments at the U. of Massachusetts. These were probably the first investigations conducted with elite athletes, several of whom went on to win Olympic medals.

The first study was on the psychological effect of these ergogenic aids. In the first half of the study, we trained all the athletes with weights. In the second half, we informed the subjects that we were putting them on steroids. We actually fed them placeboes—that is, "sugar pills".

The results were interesting—everyone improved more *when they thought they were taking steroids*! It was obvious that psychological factors influenced their performance.

The study was so intriguing that we instituted another study using a double-bind technique with the drug and the placebo. The oral anabolic steroid and the placebo were identical in appearance and were assigned to the subjects by code—with only the infirmary knowing which was which.

The subjects were divided into two equal groups. Group A received the anabolic steroid the first four weeks and the placebo the last four weeks, while Group B received the placebo and the steroid in the reverse order.

Results: The subjects improved their voluntary muscular force both with and without the anabolic steroid, but all showed greater improvement during the drug period (Journal of Applied Physiology, 1972).

The study drew a wave of criticism. Many people refused to acknowledge the findings.

As a member of the Olympic Committee for the past seven years, I (and other individuals) have critized the Committee's three-monkey approach to this important issue: see no evil, hear no evil, speak no evil. And then came Venezuela . . . .

Nobody could bury his head in the sand anymore. Our best athletes have been forced to drop out or risk disqualification.

At this point, instead of meeting with them and discussing the problem, the USOC blamed the athletes for using anabolic steroids and declared "war" on them.

The Philadelphia connection . . .

Interestingly enough, *a month before* the Pan Am Games, a group of scientifically minded people, concerned over the widespread use of drugs in Olympics sports competition and training, held a confidential conference in Philadelphia.

The group included several members and the staff of the Sports Medicine Committee, a distinguished group of consultants (including Olympic athletes and coaches, physiologists and physicians familiar with the drug problem), and representatives from Hahnemann University and the National Institutes of Alcohol and Alcoholism and Drug Abuse.

The participants agreed that many athletes throughout the world were taking steroids regularly, usually in conjunction with other drugs, and that in the power events, such as throwing and weightlifting, practically everyone was a user.

In the Soviet Union, it was reported, drug use was a standard part of the training for many sports. In the U.S., about 300,000 athletes were using steroids to improve their performance.

Another major concern of the conference was that these drugs were also being taken by younger athletes. Teenagers and children as young as eight were using steroids and growth hormones.

Trainers and physicians reported that they were receiving an increasing number of parental requests for medications that would improve the performance of their children.

The primary concern of the conference was with anabolic steroids. The UCLA toxicology laboratory has identified more than 85 types closely related to the male hormone testosterone. When originally used by athletes in the early 1960's, the dosage levels were 5 to 10 mg per day. The current practice is 50 to 100 mg daily in track and field and 500 to 1,000 mg daily in the power events.

The preponderance of evidence shows that steroids can improve the performance, often dramatically, of elite athletes who are soundly conditioned and trained.

To escape detection, the athletes cease injections about 40 days before competition and oral dosages 10 to 14 days prior to competiton. There is no data on whether steroids are fully eliminated from the body during these intervals.

The negative side effects of steroids, many of which are probably still unknown, are also matters of great concern.

The Philadelphia conference concluded that the use/misuse of drugs by athletes throughout the world was a health problem that still hadn't received full recognition, and that the drug issue was "dynamite", just waiting to explode".

It was a prophetic deduction. The "dynamite" exploded only a few weeks later at the Pan Am Games.

Solution to the Drug Problem . . .

As one of the first investigators to study elite athletes and anabolic steroids, we have never stopped looking for a solution to the drug problem. Merely *telling* the athletes that drugs are "bad" is ineffective. As indicated at the conference, most athletes are willing to sacrifice years from their lives to win the Olympic Gold.

The only effective solution to the drug problem lies in providing suitable alternatives based on our greatest strengths: innovation and technology.

Technology put Americans on the moon, created thousands of inventions, and even gave the Fosbury Flop to the world. It can also provide a technological rather than pharmaceutical "edge" for our athletes.

When an athlete takes anabolic steroids, he or she effects the retention of nitrogen, which leads to the synthesis of protein in the body. Some of the protein is incorporated into the muscular system and builds bigger and stronger muscles.

But stronger muscles alone do not assume optimum performance. The critical factor is *speed*, and steroids cannot add speed to the muscles, only force.

A recent examination of several elite athletes revealed an interesting point about their speeds. Ben Plucknett, who owns the world record in the discus; Brian Oldfield, the best shot-putter in the world; and Mac Wilkins, the discus gold medalist from Montreal, were tested for bench-press strength at several different velocities.

It was found that at a slow velocity, Plucknett was the strongest:

Plucknett—623 lbs.
Oldfield—275 lbs.
Wilkins—475 lbs.

At an intermediate velocity, Plucknett's strength decreased in comparison with the other lifters:

Plucknett—432 lbs.
Oldfield—274 lbs.
Wilkins—454 lbs.

At a higher speed, Oldfield was found to be the strongest:

Plucknett—235 lbs.
Oldfield—265 lbs.
Wilkins—245 lbs.

Other athletes were tested at the same time under identical conditions. None was able to generate the same level of force even at the lowest speed. The conclusion to be drawn is that our world-record holders have different capabilities than other athletes for generating power, and it is power, not force, which is the secret to winning.

In other words, *generating force at a high speed* is what separates the great athletes from the good ones—and *anabolic steroids cannot contribute to the development of speed*, only to muscular bulk.

Extensive research is currently being conducted (at the Coto Research Center) on the training of elite athletes with a computerized exercise machine. The focus is on determining whether training the neuromuscular system can have a greater effect than drugs on the athlete's performance goal.

Preliminary evidence indicates that significantly effective gains can be obtained from training the nervous system at velocities similar to those generated in the explosive events.

The results suggest an alternative to the steroid approach. Good old Yankee ingenuity can fill the breach. It *must* be used if we expect our athletes to continue to compete at world-class levels.

The two questions that remain are: Can we do enough and do we have the time?

STRUCTURING A WINNING TEAM WITH THE HELP OF SCIENCE

How science can help achieve maximum performance

By DR. GIDEON ARIEL / Chairman, Computer Sciences/Biomechanics, U.S. Olympic Committee

SCHOLASTIC COACH DEC. 1983

COACHES preparing for a contest will gather all the information they can on the opponent's strategy and individual strengths and weaknesses.

One of the most common devices is scouting the opponent's games and practices. If it's impossible to see every game, the coach can resort to television and game movies. This form of observation can make a valuable contribution to the coach's store of knowledge and game plan.

Unfortunately, the inherent flaw in visual observation is the difficulty of (1) quantifying the players' movements with relation to the ball and each other, and (2) obtaining statistical analyses of these movements.

This "hidden information" includes the positions of the players on the court, the ball positions, and the game strategy, plus the players' speed of movement with regard to their positions, their role in the strategy, and the speed of the ball at any point in the game.

Once this information is gleaned, the coach can proceed with cluster and density analyses of the area covered by each player, the probabilities of the various hits, passes, throws, etc., of the ball, and the reaction time and speed of movement of each player.

And that brings us to an outstanding coach named Dr. Arie Selinger. I first met Arie in 1978 at the USOC Training Center in Colorado Springs. Arie was coaching the U.S. Olympic Women's Volleyball Team which, at the time, was held in very low international esteem.

Arie and I discussed the essential elements that go into the making of a winning team, such as:

1. Understanding the basic nature of the particular game.
2. Recruiting the proper athletes.
3. Implementing specific fitness training to develop the proper energy sources required for the game.
4. Developing the proper skill level.
5. Learning and understanding the opponents' efficiencies and deficiencies.
6. Acquiring and storing data on the teams playing in the major international tournaments.
7. Simulating various game situations to improve the team's skills in these areas.
8. Implementing preventive training programs to avoid injuries and to promote rapid recovery when injuries do occur.
9. Obtaining the necessary technology for these items.
10. Obtaining financial support.

Let us look deeper into these factors, using the Women's Volleyball Team as our laboratory.

The coach must begin by studying the game from a biomechanical point of view and compiling statistical analysis on the formations used in the game—including high-speed cinematography of various national and international games.

One of the first problems encountered by Arie was to assess the vertical jumping heights of various players throughout the world. We had to determine biomechanically how they jumped and what kinds of movements they performed in volleyball. For example, we wanted to know how were the shorter Japanese able to defeat the taller Cuban team?

Another question was why all the Chinese girls were the same height, 6 feet, and did this help the setter place the ball in the same way for each of them?

How much lateral movement exists compared to horizontal movement, and are there differences among the spikers from different national teams?

This type of information takes years to gather, even with sophisticated technologies, and we are still developing new skills and techniques.

After determining the "anatomy" of the skill in his sport, the coach must still find the athletes who can do it.

The best athletes in the nation may not fit the bill. For example, when Arie started to screen for his Women's Volleyball Team, the U.S. ranked No. 54 in the world. So, if he chose the best athletes from that team, he would have guaranteed himself another No. 54 team.

Since his goal was No. 1, he had to go looking for the proper talent. He had to be coach, salesman, and psychologist.

Some of the athletes had never played softball, but possessed the inherent qualities of greatness. For example, Flo Hyman, who was 6'5" but had never played volleyball, was an early choice.

Arie explained that with his methods of training, she could become the world's greatest volleyball player. Today, after eight years of work, Flo Hyman *is* the best player in the world.

It took years to fill all the positions, but each selection was done scientifically, based on information provided through high technology. There were no "shots in the dark".

After acquiring the proper talent, Arie now had to begin the hard, time-consuming task of training. Scientific methods were required to implement the training. Merely playing the game or guessing what you were going to do next was insufficient.

Having previously assessed the skill requirements and determined the make-up of the various opponents, we concluded that the training had to be done close to sea level and on special modalities to develop the physiological factors essential to success.

The team would have to live together, practice full-time, have their own gym, have access to the best technology, and have good weather and community support.

Arie investigated various sites and chose Coto De Caza, Cal., home of the Coto Research Center and site of the Modern Pentathlon for the 1984 Olympic Games.

In addition to having the sophisticated analyses systems previously discussed, the team could also train on the computerized exercise machine, which was programmed to enhance the strength needed for quickness and proper vertical jumping.

The application of space-age technology for analysis and training is now essential for all athletes questing for Gold medals.

To achieve maximum skill levels, Arie requested biomechanical analyses for the vertical jump portion of the spike. He wanted to improve the players' vertical jump but without generating so much forward movement that the athlete would touch the net.

By simulating different positions on the computer, Arie developed a technique that allowed the players to gain vertical height at an angle which enabled them to land at a significant distance from the net.

In spiking, it was found that excessive arm movement was unnecessary and that it tipped off the direction of the spike. By eliminating this excess movement, Arie significantly increased the velocity of the spike and masked its direction.

Other skills were developed by simulating the activity on the computer screen and then adapting it to the team. Result: Most teams throughout the world began imitating the U.S. team!

Film Analysis

Understanding the opponent is not an easy task. Obviously, the Soviet Union and China are not going to share information with anyone else—the way the U.S. does. Try asking East Germany about training methods, you will be lucky to receive a response.

Arie and I decided that in order to learn about the Chinese or the Japanese, we would have to collect high-speed film at the national tournaments, such as the World Cup and the World Championship. The Russians or Chinese cannot hide their "secrets" in these games. They have to play their best, and all of this is captured on film.

This film is analyzed at the Coto Research Center, utilizing individual and team types of analysis. For the individual analysis, the heights of various jumps, the horizontal and lateral velocities of the players, the speed of the ball after the spike, and other important skills are calculated.

The formation analysis provides the coach with such vital information as where the ball is likely to land after a certain player spikes it. This "cluster" analysis allows the coach to determine the probabilities of success of a particular formation.

Arie prepared his strategy against the Japanese this way, since he knew the vulnerable areas on the court and why, under certain conditons, the Japanese do not block but utilize different defensive strategies.

Knowing these factors is like playing poker while seeing your opponent's cards.

understand not only the biomechanical factors but the philosophical and historical bases for the opponents' reactions in various situations.

For example, what makes a team "crack" or react abnormally in critical situations? Let's assume that Arie would like to play a mock game against the Chinese before actually meeting them in a major competition. Since the game situations reside in the computer, why not use holographic technology to simulate the game—have the team play against a holographic "Chinese" team?

Although our technology is not yet ready for this idea, we can use projected "silhouettes" from film taken in games. We can also "accelerate" the Russian team by 10% on the screen, thus forcing our players to adjust to this situation. Result: the Russian team will seem much slower in the actual game later on.

One of the problems in the preparation of a national team is that there's only one totally meaningful competition—the Olympic Games. An injury to one key player can destroy the team's chance to win.

A proper prevention and rehabilitation program is, therefore, essential. At the Coto Research Center, the volleyball team is utilizing the cutting edge of technology in exercise modalities for training, detecting potential problems, and rehabilitating. When, for example, we found that the players had very strong legs in contrast with the upper body, we had to adjust their resistive-training program.

The computerized exercise machine is used for exercising both the central nervous and muscular systems. The ability of these machines to control velocity and resistance allows us to tailor the program to each athlete.

The U.S. Women's Volleyball Team has proven at least one vital point—that with American technology we can beat China, East Germany, Soviet Union, Japan, Cuba, and others. *We can not do it without science.*

That's what the Japanese coach implied when he recently addressed a congratulatory letter to:

"The Computer Team, Coto Research Center, California."

THE 'BIO' SIDE OF MODERN 'BIOMECHANICS'

Analyzing the functioning of living organisms

By DR. GIDEON ARIEL / Chairman, Computer Sciences/Biomechanics, U.S. Olympic Committee

SCHOLASTIC COACH JAN. 1984

MY previous articles discussed the impact of high technology on performance and stressed the idea that the purpose of high technology was not to replace coaches but to enhance their knowledge and equipment.

One thing is for sure: Our coaches must become more sophisticated in their knowledge, equipment, and techniques. This conclusion is consistent with the Presidential report on education, as well as with the explosion in technology.

Basic scientific knowledge will become an absolute "must" for the coach. It will aid him in the selection of athletes and in the subsequent coaching of them.

In order for the coach to achieve these goals, he will need special preparation in several areas. To analyze his athletes, he will have to rely on sciences ranging from physiology, biomechanics, and psychology to high technology and sophisticated electronics. To design the best strategies to achieve his goals, he will have to use the computer as his primary tool.

Let's look at some of the basic scientific information underlying humans and their control systems. That is the "bio" side of "biomechanics". My next article will address: the factors, both external and internal, that comprise the mechanics.

The "Bio"

Human movement occurs as a series of separate individual actions—beginning with minute electro-chemical processes of incredible speed and complication.

Our muscles are thin strands of fibers which can contract or relax because of these electro-chemical reactions. The resulting movement has a fluidity that defies even the sharpest eyes to break down.

For instance, the simplest of human movements, such as crooking a finger or raising an eyebrow, involves complex neuromuscular happenings that cannot be duplicated by artificial means. The best man-made robot still moves in jerks and stops when compared to the subtle, flowing motions of a human.

The "bio" part of biomechanics perhaps more properly belongs under the subsection of biology known as physiology—the science that deals with the functioning of living organisms.

The smallest elements of the body which maintain all the functions of life are the 100 trillion cells. The cell itself has been compared to a tiny city-state. Within its microscopic confines, the cell operates industries to support itself, transports vital supplies, and rids itself of wastes. It trades with neighboring entities, yet remains prepared to repel hostile invaders.

Cells are coded for different functions; some are liver cells, others are muscle or nerve cells, etc. But one thing is constant about cells—their basic structure or anatomy is made up of the same elements. The ways in which these elements operate (physiological processes) are also the same.

It is important to realize that the human body has remained essentially unchanged for eons. All that has changed is the environment in which it functions. Our cells have to adapt to this fast-changing world.

Our anatomy is a passive system without the physiology. That is, physiology allows the anatomy to function. The linkage between anatomy and physiology is provided by the basic commodity of energy, and the use of energy is what distinguishes living matter from dead.

The physiological processes receive their energy from the food that we eat. The fats, carbohydrates and proteins, all possess energy potentials which can be converted into energy to fuel the physiological machine.

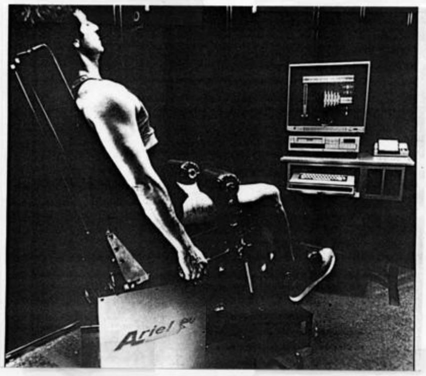
Compound ATP

The real limitation of our muscular efforts is not oxygen, as is commonly believed, but the supply of a chemical compound called ATP. When all of the ATP is gone, there is still oxygen in the bloodstream.

Without ATP, the situation is analagous to a car engine running while in neutral. In order for the muscles to be put into gear, they must be linked to the energy-producing engine by means of ATP—the transmission of the body's energy system—which contracts the muscle fibers.

The production of ATP and its energy role relates to our aerobic and anaerobic capacity. Aerobic means ATP production in the presence of oxygen, while anaerobic means ATP production in the absence of oxygen.

However, oxygen cannot do the work alone. An efficient transportation system is also needed, beginning with the pumping of blood. Aerobic capacity, therefore,



represents the efficiency of both the heart and muscle.

People who exercise regularly in endurance-type activities develop highly efficient muscles—skeletal, cardiac, and others—and biochemical reactions. The healthy person also has a different blood chemistry. His volume of blood is greater, being accommodated in a larger heart and an expanded vascular system.

The brain of all living animals serves mainly to control behavior. Only the human brain has the ability to think, create, love, etc. Thought, therefore, is not its primary purpose but, rather, just part of the complex computing mechanism required to generate and control extremely sophisticated behavior.

Sometimes, this ability to think causes inhibition in our control mechanism. This is obviously the case with athletes who fail to perform because of "mental" inhibition—"paralysis by analysis".

Some people think that the brain is a computer. However, the only computer element in the brain is the cell. Each of the 10 billion acts as a computer.

Some sensors detect touch, pressure, heat, cold, and pain.

Chemical sensors detect smell and taste.

Posture sensors detect the position of joints, tension in tendons, and length and velocity of muscle contraction.

Inertial sensors control changes in posture and acceleration of limbs as well as the relative position of the head.

Hormone, thermo, and blood chemistry analyzers report on the internal biological conditon of the whole organism.

All of this varied and continually changing information is analyzed and processed in innumerable computing centers which detect patterns, compare incoming data with stored expectations, and evaluate the results.

In many different ways and at many different levels, this sensory data stream interacts with the action-generating system to select goals, modify habits, and direct the actions of muscles, glands, and other tissue to produce what is called "behavior".

Perhaps the most obvious feature of the brain is that many computations are going on simultaneously in many different places. The brain does not execute sequential programs of instructions like a computer, but, rather, executes many parallel processes at the same time.

Muscle Groups

In addition to understanding the control of each fiber, we must understand the muscle groups as well. Muscles usually come in pairs. One is known as a flexor, the other as an extensor. When you bend your elbow, one pair of muscles contracts while the other relaxes.

A motor neuron transmission initiates the contraction, while the lack of a motor neuron transmission to the other member allows the fibers of that muscle to remain in a relaxed state.

The importance of the motor control lies not in the contraction of individual muscles, but in the coordinated contraction and relaxation of many muscles. In making a fist or grasping an object, for example, a person cannot merely flex the fingers by contracting the flexor muscles in the forearm. The extensor muscles in the forearm must also be contracted to keep the finger's flexor muscles from flexing the wrist.

The individual muscle fibers that cause a muscle to contract and relax rely on an elaborate synchronization. The arrangement permits all of them to arrive at a peak of action simultaneously.

Synchronization of muscle firing is critical for optimizing athletic performance. In the power events, such as throwing the discus or in high jumping, it is extremely important that the muscle action be simultaneously activated to optimize the force. This is done by the central nervous system sending signals to the individual muscle fibers. Lack of synchronization in power events results in lesser force and poorer performance.

On the other hand, in events of endurance, such as long-distance running, asynchronization is important, as fewer fibers are needed to maintain the action, thus permitting other fibers to "rest". In fact, the long-distance runner who "over-recruits" muscle fibers fatigues sooner. This illustrates the importance of technique in achieving optimal performance.

The question is, "How does the brain adapt to the requirement"? The answer depends upon the large number of approximations that add up to the correct signal.

The brain achieves its incredible precision and reliability through redundancy and statistical techniques. Many axons carry information concerning the value of the same variable, each encoded slightly differently. The statistical summation of these many imprecise and noisy information channels produces the reliable transmission of precise messages over long distances.

Another important factor which must be controlled is the amount of tension in a muscle. This varies according to the length of the muscle. In exercising a muscle, you'll find you can push harder when the muscle is relaxed rather than already contracted to a shorter length.

Slow/Fast Twitch

The speed with which you bring the muscle into play is another factor, as slower movement allows greater force development than fast movement. Scientists have also discovered that muscle fibers can be classified as either "slow twitch" or "fast twitch".

However, the field of histology has shown additional subdivisions and a whole spectrum of fiber characteristics. A preponderance of slow or fast twitch fibers, or an equal balance, appears to be largely a matter of genetics.

Biopsies of the tissue of world-class athletes indicate that those who lead in endurance events have a preponderance of slow-twitch fibers. Perhaps 80% of the muscles employed in their events are so characterized.

Sprinters, on the other hand, appear to have an extremely high proportion of fast-twitch fibers. This confirms the tale of the tortoise and the hare!

Distance runners thrive on slow-twitch fibers which, by contracting more slowly, consume less energy and do not fatigue as readily.

The fast-twitch fibers enable the sprinter to move his or her legs more rapidly, although a price is paid in the burning up of anerobic energy sources. For short distances, the sprinter's extravagance with energy supplies does not matter.

Recent research makes it apparent that there is a considerable diversity in the structure, biochemistry, and physiology of striated muscle fibers. Most muscles are, in fact, made up of different types of muscle fibers. Some of these are fast-contracting and others are slow.

The function of the fast-contracting fiber is perhaps obvious; it is more difficult to appreciate why muscles should have slow-contracting fibers. These slow-contracting fibers may perhaps be more efficient in certain functions.

Slow-twitch muscles are generally more economical than fast-twitch muscles in developing sustained (isometric) tension. We'd therefore expect slow fibers to be involved in maintaining posture and in movements that involve sustained tension.

When more rapid movements are required, we'd have to use fast-contracting fibers because the slow fibers are not mechanically effective at higher shortening velocities. They become inefficient once their optimum rate of shortening is exceeded.

It is thus not surprising to find that many muscles contain more than one type of fiber. In other words, muscles may possess a two- or three-"geared" system—enabling them to contract efficiently over a wide range of shortening velocities.

Could youngsters be separated into endurance-type and short-distance runners simply by studying their muscle-fiber types?

No, because most people have fairly even mixtures of fast and slow-twitch fibers. You'd think, for example, that shot-putters and high jumpers would be fast-twitch people. But they are usually characterized by a more or less even distribution of fiber types.

Investigations into slow and fast-twitch fibers are continuing. One thing seems certain, however: Proper training can improve the function of both types of muscle fiber.

There are, then, three major components of muscular contraction:

The first involves the chemical reaction that utilizes ATP.

The second relates to the force and the velocity of the muscular contraction.

The third is elasticity—the muscle's capacity to recover energy absorbed in the tissue. This elastic quality is one of the main characteristics that separates the super athlete from the average.

A relationship exists between contracting force and velocity. Muscle shortens more rapidly when it is working against lighter weights. This means that there is a damping element in the muscle that can be compared to a shock-absorber.

Since this phenomenon was first discovered, it has been suggested that something like a mechanical absorber is actually present in the muscle. It is currently thought that this damping effect is the property of the force-generating mechanism itself or, more specifically, of the interaction of the actin and myosin protein elements of muscle.

Suspension System

Tendons also have a certain amount of inherent elasticity which contributes further to muscle action. They can act like coil springs, compressing or stretching under force, then snapping back to their original length.

We thus tend to think of muscles not only as work-performing engines, but as a major suspension system for the body, giving it a "smoother ride". For example, a ballet dancer moves with a smoothness that no machine can match and a coordination and organization that no flow chart can capture.

So we see that the body is controlled and coordinated by the many industries existing within the cells, under the guidance of the nervous system. Yet, for all its complexity the human body in motion must follow the laws of mechanics described hundreds of years ago by Sir Issac Newton.

THE 'MECHANICS' IN MODERN 'BIOMECHANICS'

The mechanical laws and principles upon which optimal performance is based.

By DR. GIDEON ARIEL
Chairman, Computer Sciences/Biomechanics, U.S. Olympic Committee

SCHOLASTIC COACH FEB. 1984

LAST month's article presented the principles relating to the "bio" of the athlete. The external environmental forces ("mechanics") could be the surface on which the athlete performs or the equipment that he holds.

Other considerations might be the air resistance or the frictional forces of the surface.

The interaction between the "bio" and the "mechanics" enables the coach to optimize the athlete's performance. Unlike the "bio", which is affected by structure, anatomy, physiology, genetics, and nutrition, the "mechanics" is governed by the physical laws, or universal tenets.

Mechanical science originated with the ancient Greek scholars. One of the earliest phenomenons that aroused their curiosity was motion. The interaction between a human being and his environment is possible only through motion. However, motion does not require life, as a tennis ball can be hit or a dart thrown.

The first Greek to put the principle into sophisticated form was Aristotle. He maintained that each element on earth had its own characteristics and, therefore behaved uniquely.

The Aristotelian view of motion was accepted for a long time, but was later proved wrong. First of all, it did not deal with gravity. According to Aristotle, if a tennis ball were thrown into the air, the air itself would make the ball move. Without air, there would be no movement.

Also, according to Aristotle, different masses had different gravitational forces. This theory also failed to prove out.

The Italian scientist, Galileo Galilei (1564-1642), formulated the bases of free-falling bodies. By rolling different masses of balls across an inclined board, he found that the different weights rolled down the inclined plane at the same rate.

If the plane were tipped more sharply, the balls would roll more rapidly, but all at the same rate of speed. In the end, all would cover the same distance in the same time.

Law of Momentum

This means that freely falling bodies fall through equal distances in equal times, regardless of their weight. In short, a heavy body will not fall more rapidly than a light one.

The importance of the falling-masses experiment lies in an understanding of acceleration. As was discovered by Galileo, the distance traversed by a body rolling down an inclined plane grows greater and greater in successive equal time intervals.

This means that the rate of speed is changing, and this is precisely, what acceleration is—the change in rate of speed or, more accurately, velocity. The acceleration of free-fall bodies is a constant 32 feet per second.

It was absolutely necessary for Sir Isaac Newton to understand acceleration in formulating the laws of motion. According to Newtonian law, the acceleration produced by a particular force acting on a body is directly proportional to the magnitude of the force and inversely proportional to the mass of the body.

It is impossible to begin movement without applying force, whether it is an external force such as gravity, or an internal force such as muscular force.

For example, the force applied to a hockey puck will create an acceleration that will set the puck moving faster and faster, as long as the force is applied. The length of time that the force is applied on the puck is important.

In mechanics, the product of force and time is called an impulse. For a given mass, a given impulse will produce a particular velocity. The heavier the object, the greater the impulse needed to achieve the same velocity. It is obvious, that velocity and mass are related to each other; in fact, the product of mass and velocity is referred to as momentum.

The law of momentum is most important in contact sports, where different masses collide at different velocities. For instance, it is this law that allows a smaller football player with greater velocity to block a heavier football player with less velocity.

In the case of the hockey puck, the puck that possesses a certain mass and is speeding across the ice at a given velocity has momentum equal to its mass times its velocity. If, along its travels, it collides with another hockey puck of the same mass moving at the same speed but in the opposite direction, they will come to an instant stop.

In other words, one momentum would cancel out the other. This principle of conservation of momentum is more visible in the game of billiards, where solid balls hit others at different velocities.

Thus far, we have focused on linear movements where objects displace all their dimensions at the same rate. In the human body, however, every part is moving in rotational fashion. Take the wheel. The center remains stationary while every other part moves.

Rotational movement requires an understanding of torque, or movement—a force that gives rise to rotational movement. The amount of torque depends on the force and the distance from the center of the rotational object. The product of force and distance is equal to torque.

The conservation of angular momentum is one of the most important principles in athletic performance.

Angular momentum can be expressed in terms of two other important parameters of rotation — angular velocity and moment of inertia.

Angular velocity is represented by the body's rotational speed and direction. For example, if a diver performs a forward double somersault in one second, the magnitude of his average angular velocity is two revolutions per second.

The moment of inertia of a body about an axis is the body's tendency to resist changes in angular velocity about that axis. It is obvious that massive and extended bodies have a larger moment of inertia than do lighter and smaller ones.

Mechanical Laws

In addition to these principles, the modern coach should be familiar with the forces of friction, the different principles related to levers in the body, and the principles governing potential and kinetic energy. All these mechanical laws and principles relate directly to optimal athletic performance, though they cannot be measured by the human eye.

With the aid of the computer, each of the forces and the various motions can be quantified and measured. Several examples may serve to illustrate these principles.

An old but excellent discus thrower decided to change his style. Since he kept his arm too low, producing a loss of angular momentum, he decided to elevate the arm.

Another concern was that he turned too far with the discus and "opened" his position too soon, causing a loss of angular velocity and an overly short time of applied force (to the discus). By keeping his trunk more twisted, he found that he could achieve better pull on the discus.

Next, he determined that the coefficient of friction on his left shoe had to be minimal for the rotational movement and maximal for the linear movement. Solution: Develop a shoe which would have maximal sliding friction and minimal rotational friction.

These technological improvements immediately added about 10 feet to his throw, and, within a year, he produced his best-ever throw.

Another event which we analyzed was hurdling. Question: What is the most efficient technique in hurdling? The analysis revealed that the center of gravity should be raised only minimally above the hurdle and that the shoulders and head should be kept in a straight line to safeguard against "falling down" after passing the hurdle. Many hurdlers "jump" over the hurdle; the good ones "run through" it.

For years, coaches have debated whether the rotational style is better than the linear style in shot-putting.

From the mechanics point of view, the rotational technique allows the development of more angular momentum and angular speed. Since the release velocity is the most important critical point in achieving distance, the rotational technique was found to have greater potential.

Art and Science

Aristotle, in *Poetics*, sought to isolate the elements of drama so that he could formulate a set of rules that would assure good plays.

Athletics were also regarded as an art form by the Greeks. Today, they are accepted more as a science. Aristotle's art has yielded to the high-speed camera and the computer. Art binds the performers to tradition, and this can retard the pursuit of excellence. Instead of burdening an athlete with the baggage of the past, science seeks to enhance performance through quantification rather than beauty of form.

One generalization seems to hold: Actions that place a premium upon near maximum force—such as throwing a baseball, driving a golf ball, high-jumping, tossing the shot, swinging a bat, or, indeed, anything in which speed and distance count more than formal grace—depend upon the most efficient acceleration and deceleration of the body's link system.

If your aim is to hit a home run, drive a ball 200 yards, or high-jump seven feet, your goal can be summed up simply: "Move your mass." Move it quickly and smoothly, transmitting the force from joint to joint until the sum of all your movements of mass concentrates upon the object of your intentions.

The mechanics of movement refer to a series of constants that affects all bodies. Unlike psychology or physiology, where each individual has his own uniqueness to which the coach must adapt, the mechanics of athletics observe but one law.

The coach of the future must, therefore, understand these laws and how to apply them to the activity. The coach who can apply them best will win more often than the coach who relies on guesswork and observation.

Next month, I will discuss the interface between the "bio" and the "mechanics" in sports.