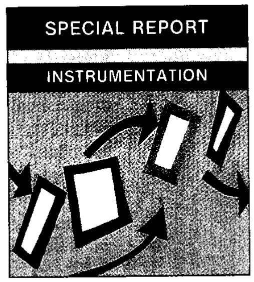
Biomechanically engineered athletes

High-speed video and personal computers have propelled motion analysis out of the ivory tower of the research laboratory and onto the athletic field



The Olympic athlete throws a javelin across the training field, where its flight is observed by a high-speed video camera connected to a workstation. The path of the javelin is digitized in real time, and within two minutes software running on the workstation calculates the javelin's position upon release, its velocity, its angle of attack, and the angular velocity of its roll through the air, and compares those values against a mathematical model of the perfect javelin throw. Analyzing the results, the coach suggests a slightly different release angle for the athlete's next throw.

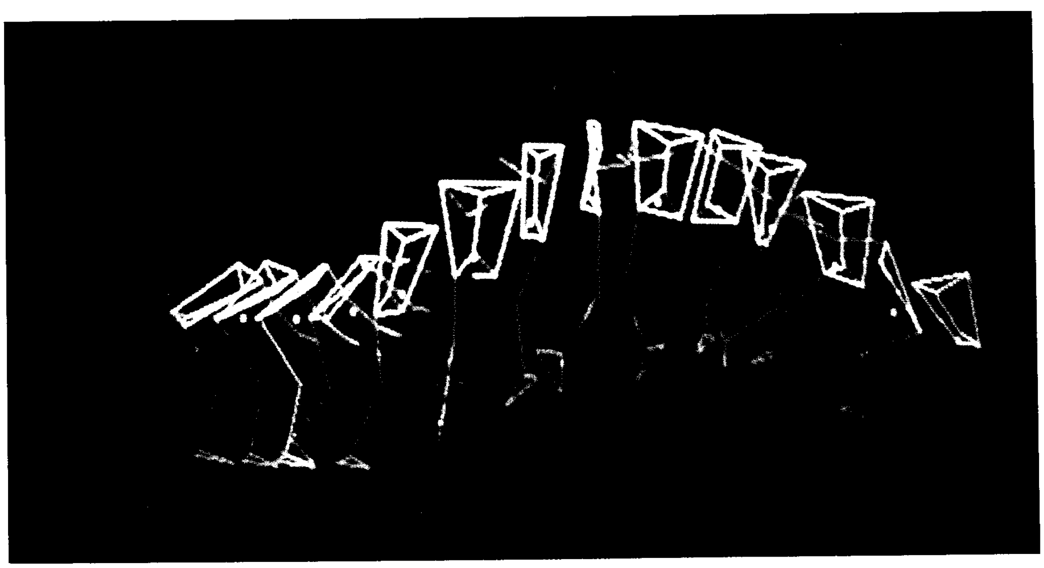
This is movement analysis, high-technology style. Already tested on decathletes, this method of breaking down human physical activity into mathematical parameters was to begin being applied to the training of elite U.S. javelin throwers at the University of California at Davis in March. Since the mid-1980s, sports biomechanics has succeeded a more cumbersome process that involved using high-speed cameras, projecting developed film on a digitizing tablet about the size of a pool table, and using a puck or pen to input coordinates into a minicomputer, so that software could calculate angles, forces, and speeds of the motion of the subjects' arms, legs, torso, or other body parts.

Previously, data gathering and analysis took too long to be applicable to individuals. Studies took the form of academic research projects, with results published after years of work to help doctors and sports trainers develop exercise programs and rehabilitation techniques. Now reasonably priced, high-speed portable video systems and computerized digitizing aids lead to results that can be quickly used.

Tekla S. Perry Senior Editor

Consequently, the field of biomechanics as applied to athletic performance is rapidly expanding. In addition to broad-based work being carried on at the U.S. Olympic Training Center (USOTC) in Colorado Springs, Colo., and Centinela Hospital Medical Center in Inglewood, Calif., many university researchers have focused biomechanical studies on one sport or event: Pennsylvania State University on running, the University of Northern Colorado on pole vaulting, the University of California at Davis on javelin and distance running, the University of Iowa on long jumping, and Indiana University on high jumping and hammer throwing. In late 1989, the First International Olympic Committee Sports Science Congress was held in Colorado Springs, and papers on movement analysis, force tests, electromyography experiments, and other biomechanical topics were presented by researchers from the United States, the Netherlands, West Germany, the United Kingdom, the USSR, Japan, Italy, Greece, the Republic of China, and other countries. The East German sports authority recently offered to sell the results of its athletic research. And private facilities, for a fee, will analyze someone's golf swing or tennis stroke. This trend is likely to continue as movement analysis systems and related devices become ever cheaper, easier to use, and more functional.

"There is," points out Leonard Jansen, head of the department of computer science at the USOTC, "no substitute for science and technology in improving athletic performance except drugs, and drugs are not acceptable."

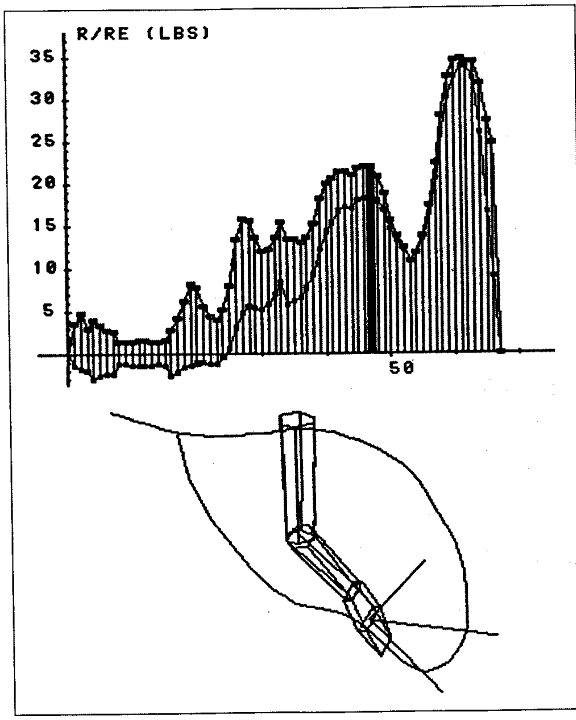


Peak Performance Technologies Inc

[1] This figure skater jumping and turning was digitized in three dimensions on an IBM PC/AT-based digitizing system from Peak Performance Technologies Inc., Englewood, Colo. Working with one video field at a time, the biomechanists use a mouse to select significant points. The system connects the points, creating stick figures. Software routines perform direct linear transformations on the two-dimensional data from each camera and convert it into three-dimensional coordinates.

0018-9235/90/0400-0043$1.00

©1990 IEEE



[2] In this excerpt from an analysis of Olympic medalist Matt Biondi's freestyle stroke made last November, the wireframe arm tracks his stroke paths, arm and hand position at one point in the stroke, and direction of force (vectors from hand). The graph shows the force created throughout his stroke (the dark bar correlates the graph to the wireframe diagram). The top curve is total force; the bottom curve is positive force. The distance between the two curves is negative (drag) force, which the swimmer attempts to minimize. By comparing this data with measurements of Biondi made in 1988 and 1984, biomechanists ascertained that he was not getting as much force at the end of his stroke as previously because his wrist was not fully extended; a correction was recommended.

In a laboratory environment, automatic digitizing systems that use video cameras connected to personal computers or workstations can capture simple motions in real time. These systems, ranging in price from $30 000 to several hundred thousand dollars, rely on reflective markers or light-emitting diodes (LEDs) to identify significant body points. Such systems are being used at sports training facilities, in university biomechanical programs, and by orthopedic hospitals. For example, California's Centinela Hospital Medical Center has used one to test knee braces on patients; the system quickly compares the effects of different braces on a patient's gait.

A system made by Motion Analysis Corp. of Santa Rosa, Calif., is typical of the reflective method of data capture. Reflective markers—as many as 30—are attached to the subject at points to be tracked. Up to four video cameras, run through a video processor to a Sun Microsystems Inc. workstation, track the markers at a rate of up to 200 hertz. If the motion is basically linear, like a walk or a run, the computer can be instructed to correlate markers to body parts, track these points by identifying pixels that exceed a certain brightness, and then connect them to create stick figures for display and analysis. However, when motion involves twisting, which can obscure markers or cause their paths to converge, the computer software can flounder. Adding cameras can help address this problem; advances in artificial analysis may someday solve it.

Taking a slightly different tack is an automatic digitizing system designed in Sweden. Called the Selspot, it uses up to 120 infrared LEDs instead of reflectors to serve as markers. While the diodes flash in a sequence at up to 10 000 times a second, a controller wired to the LEDs and to the computer allows software to keep track of which spot is lit; an infrared-sensitive camera detects the lights. Software running on a PC/AT, VAX, or VME minicomputer sorts the markers into body parts.

Truly noninvasive automatic digitizing of complex human motion, based on pattern recognition, is at least 10 years away, researchers say, probably more. The human body presents a very difficult pattern recognition problem: a joint looks different from every angle and changes with lighting conditions. Biomechanists expect an intermediate step to be the use of different-colored spots to help the computer sort out the points, though changing lighting also complicates this solution.

Connect the dots

Sports biomechanists are engineers, with backgrounds in mechanical or biomedical engineering and an extensive knowledge of the human body, or specialists with degrees in biomechanics. Many have competed in athletic events at the national level. For most data collection, they use computer-aided digitizing systems that create three-dimensional stick figures of the athletes and automatically calculate the center of gravity, angular and linear velocities, force, and relative angles [Fig. 1].

Biomechanists also use video movement analysis to gather data previously obtained only by more intrusive methods. At a recent visit to the Olympic Training Center, *IEEE Spectrum* observed a test of throwing velocity for team handball players. The speed of a ball could have been calculated with a radar gun or timing lights, but neither would have captured velocity at the critical point of release (different in every throw).

Instead, video cameras ran while 18 players took eight shots each. Biomechanists digitized only one point—the center of the ball—into two frames. Knowing the frame rate and relative size of the image (calibrated by holding a meter stick in front of the camera), the computer quickly calculated the speed.

For swimming, the key variable is force exerted by the swimmer's stroke (typically 133 newtons). Before the proliferation of movement analysis, force calculations were made by putting pads with pressure sensors on swimmers' hands, which, unfortunately, affected the hand's motion through the water. Now the U.S. Swimming Committee relies totally on movement analysis.

Biomechanists use two underwater cameras and the computer-aided digitizing system to produce the three-dimensional coordinates of the swimmer's arm movement. They manipulate that data using swimming-specific custom software to produce a wireframe sequence of arm motions and a force curve calculated from the velocity of the hand (about 0.3 meter per second in a freestyle stroke), the angle of pitch, and the speed of the swimmer or the speed of the water if the swimmer is in a flume (about 1.8 m/s in a freestyle race) [Fig. 2]. Looking at the data, coaches can quickly determine where a swimmer can increase the force generated by his stroke or should apply weights to strengthen a certain muscle.

Swimming biomechanists are videotaping athletes at most top national and international meets, as well as during controlled tests in the flume. They hope to put their cameras in the water at the 1992 Olympics. Movement analysis of elite swimmers then can provide training guidelines for younger swimmers.

To probe further

Detailed results of many biomechanical studies are published in the *Proceedings of the First IOC World Congress on Sport Sciences*, held in 1989. Copies cost $25 from the U.S. Olympic Committee, Department of Education Services, 1750 East Boulder St., Colorado Springs, Colo. 80909; 719-578-4575.

The IEEE Engineering in Medicine and Biology Society publishes the *IEEE Transactions on Biomedical Engineering.* ◆