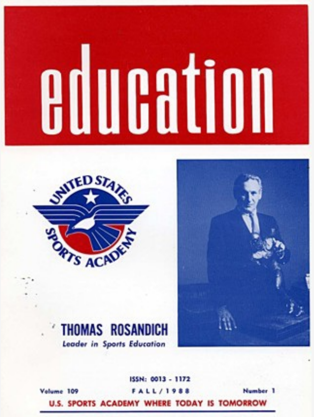
Education

United States Sports Academy



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education

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THOMAS ROSANDICH
Leader in Sports Education

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BIOMECHANICS OF EXERCISE FITNESS

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Fitness technology, in both theory and practice, exhibits two problems common to many modern, rapidly emerging disciplines. First, a lack of clearly defined and commonly accepted standards has resulted in a marketplace rife with conflicting claims and approaches to both attaining and maintaining fitness. In general, both vendors and consumers of fitness technology have been unable to provide a sound scientific answer to the simple question, "Are we doing the right thing?" Second, a lack of the proper tools and techniques for measuring fitness and the effectiveness of a given technology to the attainment of fitness has made it quite difficult to evaluate existing products in order to select the ones that really work.

The most promising approach to the solution of these problems lies in both the theoretical and practical application of the principles of biomechanics. Quite simply, biomechanics is the study of the motion of living things. As an established discipline, it has evolved from a fusion of the more classic disciplines of anatomy, physiology, physics, and engineering. As such, it is built on a sound foundation of knowledge and on the application of basic and irrefutable physical laws. Using biomechanics, one can take a new and more productive approach to the quantification and assessment of fitness. It has been a common practice to measure fitness in terms of muscular strength, cardiovascular capacity, body composition, or other tests performed on individuals. Individually or collectively, these test produce an incomplete determination of fitness. Perhaps a more appropriate definition of fitness would be the ability to perform the actual physical activities of life. The goal of fitness technology then becomes the optimization of human performance, and existing technology can be evaluated based on its ability to produce measurable gains in performance.

The Ariel Performance Analysis System

The Ariel Performance Analysis System

is a computer-based system for the measurement, analysis, and presentation of human performance. The underlying theory models the human body as a mechanical system of moving "links" upon which muscular, gravitational, inertial, and reaction forces are applied. The physical and mathematical model for such a system, although complex, is well defined. In practice, however, the problem has been the inability to accurately measure the motion parameters of the human body in three dimensions and in real time outside of the restrictive and artificial environment of the laboratory.

The Ariel Analysis System provides a means of measuring human motion based on a proprietary technique for the processing of multiple high-speed film or video recordings of a subject's performance. This technique demonstrates significant advantages over other common approaches to the measurement of human performance. First, it is noninvasive. No wires, sensors, or markers need be attached to the subject. In fact, the subject need not be aware that data are being collected. Second, it is portable and does not require modification of the performing environment. Cameras can be taken to the location of the activity and positioned in any convenient manner so as not to interfere with the subject. Activities in the workplace, the home, the hospital or clinic, or even the athletic field may be studied with equal ease. Third, the scale and accuracy of measurement can be set to whatever levels are required for the activity being performed. Camera placement, lens selection, shutter, and film speed may be varied within wide limits to collect data on motion of only a few centimeters or of many meters, with a duration from a few milliseconds to a number of seconds. For many applications, simple video cameras are sufficient for accurate motion analysis, although special applications may require very high-speed cameras, powerful lenses, and high levels of illumination. The user need only invest in the level of technology required to meet the problem at hand.

A typical performance analysis consists of four distinct phases--data collection (filming), digitizing, computation, and presentation of results. Data collection is the only phase that is not computerized. In this phase, simultaneous film or video recordings of an activity are made using two or more cameras. Only a few simple rules must be followed during data collection: (1) the cameras must not move during the activity or between the recording of the activity and the recording of the calibration points; (2) the activity must be clearly seen throughout its duration from at least two camera views; (3) the location of at least six fixed noncoplanar points visible from each cameras view (calibration points) must be known. These points need not be present during the activity as long as they can be seen before or after the activity. Usually they are provided by some object or "apparatus" of known dimensions that is placed in the general area of the activity, filmed, and then removed; (4) the speed of each of the cameras (frames/second) must be accurately known, although the speeds do not have to be the same; and (5) some event or time signal must be recorded simultaneously by all cameras during the activity in order to provide synchronization.

These rules for data collection allow great flexibility in the recording of an activity. The camera location, camera orientation, distance from camera to subject, and focal length of the lens need not be known! The image space is "self-calibrating" through the use of calibration points that do not need to be present during the activity. Different types of cameras and different film speeds may be used, and the cameras do not need to be mechanically or electronically synchronized. The best results are obtained when camera viewing axes are orthogonal (90° apart) but variations of 20° or 30° can be accommodated while introducing almost negligible error.

Digitizing is the second phase of analysis. In this phase the film or video recording from each camera is displayed, one frame at a time, on a digitizing screen. Using a stylus or a video cursor, the location of each of the

subject's body joints (e.g., ankle, knee, hip, shoulder, elbow) is measured and entered into the computer. In addition, a fixed point, which is a point in the field of view that does not move, is digitized for each frame as an absolute reference. This allows for the simple correction of any registration or vibration errors introduced during recording or playback. Finally, at some point during the digitizing of each view, a synchronizing event must be identified, and additionally the location of the calibration points as seen from that camera must be digitized and saved in computer memory. Digitizing is primarily a manual process. It is performed, however, under computer control and the digitizing of video images is computer assisted. A great deal of error checking and visual feedback is provided to speed the digitizing process and reduce the chance of error. A trained operator with a reasonable knowledge of anatomy and a consistent pattern of digitizing can rapidly product high-quality digitized images.

The computation phase of analysis is performed after all camera views have been digitized. The purpose of his phase is to compute the true three-dimensional image space coordinates of the subject's body joints from the two-dimensional digitized coordinates of each camera's view. Computation is performed using a direct linear transformation. This transformation is determined by first relating the known image space locations of the calibration points to the digitized coordinate locations of those points. The transformation is then applied to the digitized body joint locations to yield true image space locations. This process is performed under computer control with a small amount of timing information provided by the user. This information includes starting and ending points if all the data are not to be used as well as a frame rate for the image sequence that may differ from the frame rates of the cameras used to record the sequence.

When transformation is complete, a smoothing or filtering operation is performed on the image coordinates to remove small random digitizing errors and to compute body joint velocities and accelerations. Smoothing may be performed automatically by the computer or interactively with the user controlling the amount of smoothing applied to each joint. In addition, error measurements from the digitizing phase may be used to optimize the amount of smoothing selected. At the completion of smoothing the true three-dimensional body joint displacements, velocities, and accelerations have been computed on a continuous basis throughout the duration of the sequence.

At this point, optional kinetic calculations may be performed to complete the computation phase. Body joint displacements, velocities, and accelerations are combined with body segment mass distribution to compute dynamic forces and moments at each of the body joints. Muscular contribution to these forces and moments can then be computed by selectively removing the inertial and gravitational kinetic components.

The presentation phase of analysis allows computed results to be viewed and recorded in a number of different formats. Body position and body motion can be presented in both still frame and animated "stock figure" format in three dimensions. Figure 1 illustrates a typical stick figure image. Multiple stick figures may be displayed simultaneously for comparison purposes. Joint velocity and acceleration vectors may be

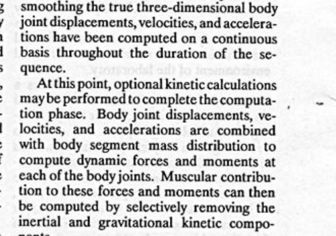


Figure 1. Multiple stick figure image of runner.

added to the stick figures to show the magnitude and direction of body motion parameters. Color hard copies of these displays can also be produced for reporting and publication.

Results can also be reported graphically. Plots of body joint and segment linear and angular displacements, velocities, accelerations, forces, and moments can be produced in a number of format options. An interactive graphically oriented user interface makes the selection and plotting of such results simple and straightforward. In addition, results may also be reported in numerical form. All quantities that can be selected for graphing may also be printed in tables of body motion parameters.

Application of Performance Analysis to Fitness Assessment

Two case studies will be utilized to illustrate the application of performance analysis to the assessment of fitness as measured by the ability to perform a certain activity. These studies closely parallel actual analyses performed using the Ariel Analysis System. The first case involved a professional football placekicker recovering from a leg injury. Proper medical diagnosis and treatment were initiated at the time of the injury, following which the athlete began a program os physical therapy to rehabilitate his leg. Subsequently, the athlete and the team management disagreed regarding the placekicker's fitness for competition. The athlete, concerned over his professional future and salary bargaining position, felt he was ready to play. The management, concerned with protecting their investment in this player, felt that it would be better to wait. A medical examination and strength tests performed with weights indicated that the leg was substantially improved. These tests, however, were insufficient for the determination of functional fitness.

High-speed motion pictures of the athlete performing a number of placekicks were taken and analyzed in conjunction with ac-

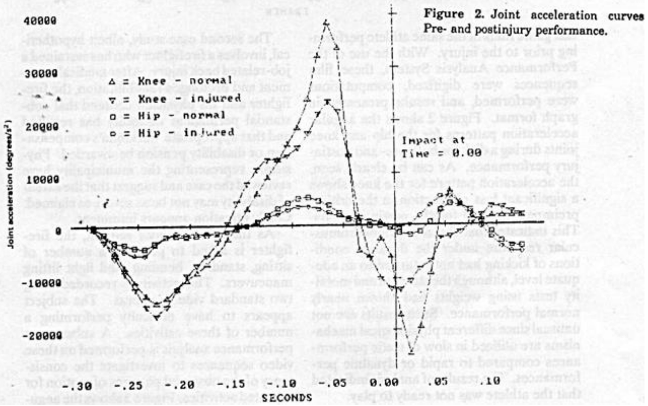


Figure 2. Joint acceleration curves Pre- and postinjury performance.

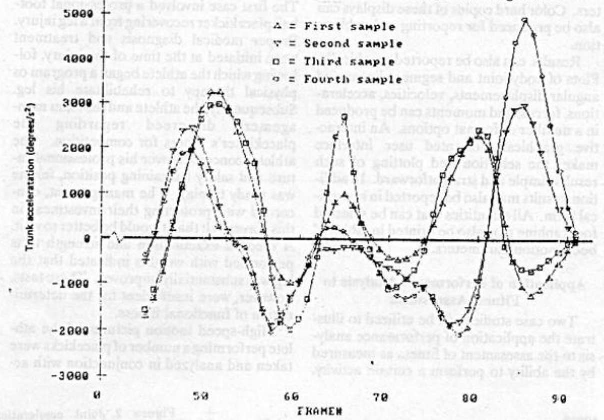


Figure 3. Trunk acceleration curves; consecutive samples, bending motion.

tual game films of the same athlete performing prior to the injury. With the use of the Performance Analysis System, these film sequences were digitized, computations were performed, and results presented in graph format. Figure 2 shows the angular acceleration patterns for the hip and knee joints during a dick for both pre- and postinjury performance. As can be clearly seen, the acceleration pattern for the knee shows a significant loss of function in the critical preimpact interval for the postinjury data. This indicates that the athlete's neuromuscular response under the dynamic conditions of kicking had not returned to an adequate level, although the strength and mobility tests using weights had shown nearly normal performance. Such results are not unusual since different physiological mechanisms are utilized in slow of static performances compared to rapid or dynamic performances. The results of analysis indicated that the athlete was not ready to play.

The second case study, albeit hypothetical, involves a firefighter who has sustained a job-related back injury. After medical treatment and prolonged rehabilitation, the firefighter and his physician contend that substantial permanent disability has resulted and that appropriate workman's compensation or disability pension be awarded. Physicians representing the municipality have reviewed the case and suggest that the extent of disability may not be as severe as claimed. Costly litigation appears imminent.

As the municipality's request, the firefighter is asked to perform a number of sitting, standing, bending, and light lifting maneuvers. This activity is recorded using two standard video cameras. The subject appears to have difficulty performing a number of these activities. A subsequent performance analysis is performed on these video sequences to investigate the consistency of the observed patterns of motion for repeated activities. Figure 3 shows the angu-

lar acceleration curves for the trunk segment for four repetitions of a simple bending and straightening activity. Each of the curves shows instances of abrupt change in acceleration allegedly resulting from pain or discomfort experienced by the subject as a result of injury. However, as can be clearly seen, the timing and shape of each of the four "pain" areas are different. In actual cases of injury of dysfunction, motion patterns representing neuromuscular activity are highly consistent. The magnitude of a given activity may change, but the pattern of acceleration is almost like a "signature" and should not change in a significant manner. The results of the performance analysis strongly indicate that the fireman is exaggerating the extent of his disability. The municipality can now seek a more reasonable settlement.

The Ariel Computerized Exercise System

The preceding discussion has illustrated the application of biomechanics to the quantification of functional fitness. Our original goal, however, was the application of fitness technology to improving or optimizing fitness. The question to be answered is:"What type of fitness technology can be shown, based on the principles of biomechanics, to be most effective in achieving specific fitness goals?"

The Ariel Computerized Exercise System is the first resistive training and rehabilitation device to employ computerized feedback control of both resistance and motion during exercise. The Ariel Exercise System, for the first time, allows the machine to dynamically adapt to the activity being performed rather than the traditional approach of modifying the activity to conform to the limitations of the machine. The case studies in applied biomechanics demonstrate the importance of considering the true patterns of motion in determining fitness. Of equal importance is the need to maintain the same pattern of motion in training or rehabilitation as that required to perform the actual activity. Prior to the introduction of the Ariel Exercise System, resistive training technology was unable to achieve this basic requirement.

The Ariel Computerized Exercise System consists of a number of training/rehabilitation units designed to accommodate varying types of body and limb movement. Each unit utilizes a passive hydraulic resistance mechanism operating in a feedback-controlled mode under the direction of the system's computer. A simplified functional description of this mechanism and its operation using feedback control is described in the following paragraph.

A standard hydraulic cylinder is attached to an exercise bar by a mechanical linkage. As the bar is moved. the piston in the hydraulic cylinder moves pushing oil out of one side of the cylinder, through a valve, and back into the other side of the cylinder. When the valve is fully open there is no resistance to the movement of oil and thus no resistance to the movement of the bar. As the valve is closed, it becomes harder to push the oil from one side of the cylinder to the other and thus harder to move the bar. When the valve is fully closed, oil cannot flow and the bar will not move. In addition to the cylinder, the resistance mechanism contains sensors to measure the applied force on the bar and the motion of the bar. Now assume the valve is at some intermediate position and the bar is being moved at some velocity with some level of resistance. If the computer senses that the bar velocity is too high or that bar resistance is too low, it will close the valve by a small amount and then check the velocity and resistance values again. If the values are not correct, it will continue to close the valve and check the values until the desired velocity or resistance is achieved. Similarly, if the bar velocity is too low or the bar resistance is too high, the computer will open the valve by a small amount and then recheck the values. This feedback loop will continue with the valve being opened by small amounts until desired velocity or resistance is achieved. The feedback cycle occurs hundreds of times a second so that the user will not experience perceptible variations from the desired parameters of exercise.

There are a number of advantages in such

a resistance mechanism over devices that employ weights, springs, or active components such as motors or pumps. One significant advantage is safety. The passive hydraulic mechanism provides resistance only when the user pushes of pulls against it. The user may stop exercising at any time, such as during rehabilitation if pain or discomfort is experienced, and the exercise bar will remain motionless. With other equipment types providing active resistance, the bar will continue to push against the user and possibly cause injury. Another advantage is that of bidirectional exercise. The hydraulic mechanism can provide resistance with the bar moving in either direction, whereas weights and springs provide resistance in only one direction. Opposing muscle groups can be trained in a single exercise. Two additional problems associated with weight training, noise and inertia, are also eliminated. The hydraulic mechanism is virtually silent and full resistance is maintained at all speeds. With weights, users commonly "cheat" by moving the bar more rapidly at the beginning of a stroke and then "coasting" to the end of the stroke.

In addition to the advantages just described, the primary advantage of this resistive mechanism is that the pattern of resistance or the pattern of motion experienced by the user during exercise is fully programmable. The concept of applying a pattern of resistance or motion to training and rehabilitation is new to many practitioners in these fields. Prior to the introduction of computerized feedback control, fitness technology could provide only limited modes of resistance and motion. Barbells or weights of any type can provide an isotonic or constant resistance type of training only when moved at a constant velocity. Typically, users are instructed to more the weights slowly up and down in order to avoid the problem of inertia resulting from the acceleration or deceleration of mass. Weights used with cams or linkages that vary mechanical advantage can provide a form of variable resistance, but the pattern is always fixed and the varying mechanical advantage causes a variation in velocity that increases inertial effects. Users must move the weights even more slowly to preserve the resistance pattern. This type of exercise is "artificial" in that it does not approximate the body or limb motion pattern of any actual activity.

Isokinetic or constant velocity training equipment is a relatively new fitness technology that has enjoyed wide acceptance, especially in the field of rehabilitation. These mechanisms typically utilize active or passive hydraulics or electric motors and velocity-controlling circuitry. The user or practitioner selects a constant level of velocity for exercise and the mechanism maintains this velocity while measuring the force exerted by the subject. Devices of this type eliminate the inertia problems associated with weights, allow training at velocity levels that more closely approximate actual activities, and provide a means for recording and reporting performance. Although demonstrating significant advantages over weight-based systems, isokinetic systems, by design, contain a serious limitation. There are virtually no human activities that are performed at a constant velocity. The very nature of movement requires continual acceleration and deceleration. When a person learns to walk, ride a bike, or even sign his name, he is "programming" a pattern of acceleration that may be repeated at different rates and with different levels of force, but always with the same pattern unique to that activity. To train, rehabilitate, or diagnose at a constant velocity is to change the very nature of the activity being performed.

The Ariel Exercise System has been designed to consider every movement or exercise performed by a user to be a pattern of continuously varying velocity or resistance. This pattern may be set using direct measurement of subject motion by the system, it may be copied from the results of performance analysis, or the pattern may be "designed" or created by the user or practitioner as a goal of training or rehabilitation. Exercise patterns are stored in computer memory and can be recalled and used each time a subject trains. During exercise, the computer uses the pattern to adjust bar velocity or bar resistance as the subject moves through the full range of motion. In this manner, the motion parameters of almost any activity can be closely duplicated by the exercise system. Thus, assessment, training, or rehabilitation may be performed using the same pattern as the activity itself.

The Computerized Exercise System contains numerous features to enhance the application of this advanced fitness technology. Individual exercise or rehabilitation programs, which are sequences of exercises, can be created and saved on computer diskette. Users can perform their individual program at any time merely by inserting their diskette in the computer. Measurements of exercise results are automatically saved on the same diskettes and progress is monitored by comparing current performance levels to previous ones. Performance can be measured and saved in terms of strength, speed, power, repetitions, quantity of work, endurance, and fatigue. Comparisons of these quantities can be made for flexors versus extensors, right limb versus left limb, as well as between different dates and different individuals. Visual and audio feedback are provided during exercise to ensure that the subject is training in the proper manner and to provide motivation for optimal performance.

Integration of Performance Analysis and Computerized Exercise in Achieving Optimum Fitness

The value of applying the principles of biomechanics to the assessment of fitness has been clearly demonstrated. Performance analysis provides the means to quantify human activity and to provide insight into the mechanisms that contribute either to superior or inferior levels of performance. At the same time, it has been shown that fitness technology has, for the most part, failed to promote optimum fitness because subjects are trained in a manner substantially different from that in which they perform. Finally, a new fitness technology has been presented that permits exercise and rehabilitation patterns to biomechanically duplicate the target activity. Whet remains is the practical application of these related technologies of analysis and exercise to the attainment of optimal fitness.

Our first cast study related fitness to the ability to perform a certain activity -- football placekicking. Pre- and post injury performance analysis demonstrated that although "traditional" rehabilitation was able to restore strength and mobility, the full dynamic kicking motion was not restored. With use of the Computerized Exercise System, the athlete's rehabilitation program should be enhanced to include leg extension exercises that simulate the kicking motion. These exercises will control the pattern of velocity while allowing the subject to exert whatever level of force he is capable of producing. At first, force levels will be low, especially at high velocities. As rehabilitation progresses, force levels will rise while the same pattern of motion is maintained. When levels reach acceptable values, the player has demonstrated, through the performance of the exercise, that he is ready to compete.

Optimization of fitness does not stop here. Performance analysis could be used to compare the subject's superior kicks to inferior ones to determine the parameters of motion that contribute to the best kicks. Alternatively, other placekickers with better performance could be studied to determine if their advantage lies in better technique or in a higher level of conditioning, such as strength and speed. A new training program could then be established on the Computerized Exercise System to develop modified patterns of kicking or higher levels of strength and speed so that the kicker can attain his maximum potential.

Our second case study introduces an area of even greater potential application for performance analysis and computerized rehabilitation. Work-related injuries seldom result in total disability. The typical problem facing physicians and insurance carriers is the determination of the extent of disability or loss of job-related performance.

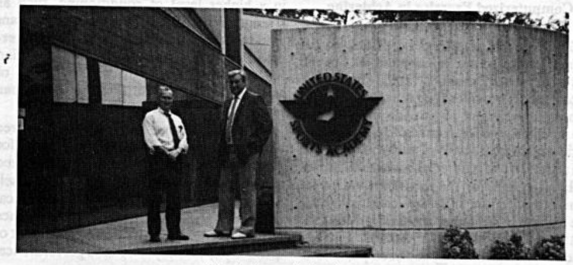
Using performance analysis, standards could be established for a number of common professions through population studies. minimal requirements for basic motion patterns could be determined through cinematography, while strength and endurance baselines could be established by the performance of similar patterns on the Computerized Exercise System. In cases of injury, analysis and exercise measurements could then be compared to these standards to quantify loss of ability to perform a specific job. Objective evidence of this type should contribute both to the reduction in litigation costs and to more equitable compensation awards.

Again, the goal of fitness technology is the promotion of fitness. Quantification of disability is only the first step in the application of this technology. Specific performance parameter measurements for various occupations coupled with actual performance analysis of individual disability will allow better rehabilitation programs to be established. The Ariel Exercise System can provide individually tailored exercise and training programs to rehabilitate subjects through a series of known performance levels. At the attainment of each level, the individual would be qualified for additional occupational activity. Not all individuals would recover full preinjury performance levels, but each person could advance to the fullest level allowed by medical and physiological limitations.

Finally, fitness technology could be applied to the reduction of debilitation injuries in the workplace through proper fitness maintenance. Periodic performance assessments could indicate potential risks when patterns of motion or levels of strength and mobility change. Employer-sponsored training programs tailored to occupation-specific requirements could be encouraged. Employees participating in such programs could be offered economic incentives based on the reduction in insurance costs and compensation claims. Better screening of job applicants in high-risk professions could be accomplished through performance analysis and computerized testing.

Fitness technology will continue to make rapid advances in the coming years. Awareness of the importance of attaining and maintaining proper fitness will continue to increase as individuals and institutions observe and experience the benefits thereof. Economic and social pressures will make ill-considered adoption of fitness technology increasingly likely. It is, therefore, important to investigate and validate new methods and technologies before they are applied. Only by maintaining a clear view of the scientific basis for our methods and procedures can we ensure that we will continue to make wise choices in attaining the goal of optimal human performance.

GIDEON B. ARIEL
Coto Research Center



Front view of Academy

UNITED STATES SPORTS ACADEMY

UNITED STATES SPORTS ACADEMY

"America's Graduate School of Sport"

ACADEMIC DISCIPLINES

Admissions

Student applicants must have a bachelor's degree and should have educational and experiential backgrounds in the area in which they plan to study. Full standing admission requires 2.75 undergraduate standing on a 4.0 scale. Students below 2.75 are subject to provisional or student-at-large acceptance. Regardless, both national and international students are encouraged to apply for educational evaluation.

Disciplines

As a new student, you will join approximately 300 fellow graduates from around the world enrolling in one of the following disciplines:

- **Sport Coaching**
Designed to prepare students scientifically for a leadership role in the dynamic field of coaching individual and team sports, at all levels.

- **Sport Fitness Management**
Designed to prepare students for careers in America's new $80 billion "wellness" industry (preventive medicine) which spans all lifestyles from the housewife to the corporate executive and indeed the professional athlete.

- **Sport Management**
Designed to prepare students for an increasing number of career opportunities in leadership positions in the field of sport and recreation management.

- **Sports Medicine**
Designed to prepare students for professional positions in clinics, high schools, colleges, universities, and hospitals.

- **Sport Research**
Designed as a pre-doctoral program for students interested in advanced discipline-oriented studies in either exercise physiology or sport behavior. Program objectives prepare the student for further studies directed toward a Ph.D. and subsequent careers in academic/research endeavors.

Faculty and Staff

The Academy's faculty and administrative staff are more than educators. They are scholars and counselors concerned with helping you develop your intellectual capacity by seeking relevant answers to difficult questions in today's complex world of sport.

The chairmen and staff play a key role in advising you academically and assisting you in career planning and are particularly interested in how you evaluate, understand, and assimilate each of your career decisions, particularly as they relate to your personal program design.

In addition to the resident faculty, the Academy has assembled a most distinguished group of sport educators, covering all aspects of sport from architecture to yachting.

This National Faculty plays a critical role in the Academy's mentor study as well as its sport education centers.

Library Learning Center and Computer Laboratory

The Academy maintains a special collections library for student research. The collection includes reference materials, books, periodicals, and journals, films, audio cassettes, video cassettes, and vertical file materials on sport and related topics. The library also participates in on-line computerized data search programs: MEDLARS, ORBIT, and BRS. These systems allow students to computer-search over 100 separate databases containing over 60 million citations in sport and sport-related areas.