CHAPTER 1

INTRODUCTION:
The Limits of Human Performance

What are the limits of physical performance? Can the discus be hurled 300 feet (Figure 1-1)? Is it possible to run the 100-m dash in 9 seconds (Figure 1-2)? Can the mile be run in less than 3 minutes (Figure 1-3)? Is it possible to swim 100 meters in less than 40 seconds? Can exercise training be used to retard the advance of coronary heart disease and other illnesses, increasing vitality and extending the life span, and can the paralyzed limbs of paraplegics be exercised to prevent their further deterioration (Figure 1-4)? Are these goals unrealistic, or do they underestimate the limits of human performance? These are important questions, of interest not only to physiologists, biochemists, molecular biologists, physicians, nurses, physical therapists, human factors engineers, physical anthropologists, and zoologists but also to sports scientists, physical educators, and athletics coaches.

Based on the principles of physiology as applied to training, the answers to the questions just posed are somewhat predictable. A shot-putter, for example, who is able to propel a shot a distance of

Figure 1-1 Al Oerter has won four Olympic gold medals in the discus. Throwing the discus over 200 feet requires enormous power, coordination, and technique. It also requires use of the immediate (phosphagen) energy system. Photo: © Wayne Glusker.

Figure 1-2 Jesse Owens in action during the 1936 Olympics in Berlin. Owens was dubbed the "world's fastest human." Such tremendous physical performance requires use of the immediate (phosphagen) and nonoxidative (glycolytic) energy systems. PHOTO: AP/Wide World Photos.

Figure 1-3 Over fifty years ago, Sir Roger Bannister was the first person to run the mile under 4 minutes. Athletic feats such as this possibly represent the supreme example of speed, power, and endurance in human endeavor. The immediate, nonoxidative and oxidative energy systems are all involved in competitive mile racing. PHOTO: © UPI/Corbis.

80 feet has to generate the necessary force to propel the implement that distance. An athlete with insufficient muscle mass, less than optimal leverage, and inadequate metabolic capability will simply be incapable of this feat. Similarly, individuals with poor cardiovascular capacity, muscular strength, metabolism, and coordination will lead physically restricted lives. The study of exercise physiology can lead to a better understanding of the physical capabilities and limitations of the human body, as well as of its underlying mechanisms.

■ The Scientific Basis of Exercise Physiology: Some Definitions

The scientific method involves the systematic solution of problems. The scientific approach to solving a problem involves the development and presentation of ideas, or hypotheses; the collection of information (data) relevant to those hypotheses; and the acceptance or rejection of the hypotheses based on evaluation of the data (conclusions). Although the scientific method appears to be straightforward, the process of deriving appropriate hypotheses and sys-

Figure 1-4 This young woman suffered three transections of her spinal cord in an automobile accident. She is shown pedaling a cycle around the Wright State University campus by means of computer-controlled, functional electrical stimulation of her paralyzed leg muscles. PHOTO: Courtesy of Roger Glaser.

tematically testing them can be complex. It is nevertheless evident that, in our increasingly technological society, those who systematically analyze their problems and take appropriate steps to solve them are most likely to acquire satisfactory answers to their questions. Individuals who make the best use of the scientific method are the most successful scientists, educators, coaches, and health professionals.

Physiology is a branch of biological science concerned with the function of organisms and their parts. The study of physiology depends on and is intertwined with other disciplines, such as anatomy, biochemistry, molecular biology, and biophysics. This interdependence is based on the fact that the human body follows the natural laws of structure and function, which fall within the domain of these other disciplines.

Exercise physiology is a branch of physiology that deals with the functioning of the body during exercise. As we shall see, definite physiological responses to exercise depend on the intensity, duration, and frequency of the exercise and the environmental circumstances, diet, health, and physiological status of the individual.

Physiological Science in Sports Science and Medicine, the Health Care Professions, Physical Education, and Athletics

One might ask, "Are physical educators, coaches, physicians and other clinicians, and practitioners scientists?" The answer depends on his or her approach to problem solving. Teachers and coaches who systematically evaluate their selection and training of individuals can be considered sports scientists. The sports scientist introduces an exercise stimulus and systematically evaluates the response. The nonscientist, in contrast, administers the training problem according to whim—such as mimicking the techniques of successful athletes—or by conforming tenaciously to traditional practices. Although nonscientists are sometimes successful, they are rarely innovative and seldom help an individual perform optimally. Moreover, their accomplishment is episodic, and they rarely sustain success in training athletes. For progress to occur in any field, systematic innovation is absolutely essential.

One might also ask, "Are physicians, physical therapists, nurses, and other health care professionals sports scientists?" Again, the answer depends on the person's approach to improving the condition of his or her patients. Are health care practitioners aware of the preventive and regenerative effects of exercise? Are they aware of principles of exercise training such as overload and specificity?

Do they seek to motivate their patients and clients personally and through design of a well-structured exercise and dietary program? Today, many successful physicians and other health care professionals evaluate their patients as successful coaches evaluate their athletes. Thus, in recent years there has been a tremendous convergence in the science and practices of preventive medicine and coaching. This convergence has centered around the science of exercise physiology.

Exercise and sport, particularly individual sports that demand extremes of strength, coordination, speed, or power, lend themselves to scientific analysis because the measures of success are easily quantified. If a weight-lifting coach attempts to improve a particular athlete's performance with a specific training technique, the results can be evaluated objectively: The athlete either improves or does not improve. Likewise, the distance a discus is thrown can be measured, the duration of a 100-m run can be timed, the number of baskets sunk in a game can be counted, and the distance an amputee can walk can be measured. The sports scientist and health science professional observe and quantify the factors affecting human performance and systematically vary them to achieve success. Admittedly, it is easier to predict performance in individual sports than in team sports or activities in which group interactions and extremes in environment operate to influence the outcome. It is not beyond the scope of our imagination, however, that, with continued development of exercise physiology and other branches of exercise science, it may someday be as possible to predict outcomes in team sports as in individual endeavors.

■ The Relevance of Physiology for the Health Care Professions, Physical Education, and Athletics

Understanding the functioning of the body during exercise is a primary responsibility of each sports scientist whether they be exercise physiologist, physical educator, coach, or health science professional. In sports, athletes and coaches who want to maximize performance require a knowledge of physiological processes. As competition in sports becomes more intense, continued improvement will be attained only by careful consideration of the most efficient means of attaining biological adaptation.

Exercise physiologists, sports scientists, and health science professionals increasingly work with more and more diverse populations—new populations interested in assuming an active lifestyle and even in participating in competitive sports. Older adults flock to masters' sporting events; heart attack patients resume physical activity earlier than ever, geriatric populations weight-train to maintain muscle mass and strength, and people with diseases such as asthma and diabetes use exercise to reduce the effects of their disabilities. These people all need guidance by trained professionals who understand responses to exercise in a variety of circumstances. Knowledge of exercise responses in these diverse populations requires a thorough understanding of both normal and abnormal physiology.

Exercise is also important to those with chronic degenerative diseases such as coronary heart disease, Type 2 Diabetes, and osteoarthritis, which have replaced infectious diseases as primary health problems. Many of these degenerative disorders are amenable to change through modification of lifestyle, such as participation in regular exercise.

The importance of exercise in a program of preventive and rehabilitative medicine has reinforced the role of the physical educator as part of the interdisciplinary team concerned with health care and maintenance. The exercise physiologist, sports scientist, physical educator, physical therapist, team physician, and other health care professionals must speak the "language of the science" to become true professionals and interact with the other professionals on the health care team.

■ The Body as a Machine

In many ways the exercising human can be compared to a machine such as an automobile. The machine converts one form of energy into another in performing work; likewise, the human converts chemical energy to mechanical energy in the process of running, throwing, and jumping. Like a machine, a human can increase exercise intensity by increasing the rate at which energy is converted from one form to another. An athlete, for example, goes faster by increasing metabolic rate and speeding the breakdown of fuels, which provides more energy for muscular work.

At their roots, motor activities are based on principles of bioenergetics, which control and limit the performance of physical activities. In this sense, the body is a machine. When exercise starts, the mechanisms of performance are determined by physical and chemical factors. Understanding how to select and prepare the biological apparatus for exercise and how the exercise affects the machine over both the short and long term is important in exercise physiology and other fields.

This book emphasizes understanding the individual during exercise from the standpoint of the energetic systems that support the various activities. The discussion begins with energy and its importance to living organisms, emphasizing how we acquire, conserve, store, and release energy for everyday life. The functions of various physiological systems (ventilatory, circulatory, endocrine, and so on) are examined from the perspective of their function in supporting physical performance and their place in the process of energy conversion. Discussion of immediate as well as the long-term effects of exercise is integrated throughout the text. We begin with some background information on the general principles of physiological response and the field of exercise physiology.

■ The Rate-Limiting Factor

In a complex biological machine such as an exercising human, many physiological processes occur simultaneously. For example, when a person runs a mile, the heart's contractility and beating frequency increase, hormones are secreted, the metabolic rate increases, and body temperature is elevated. Despite the vast number of events occurring simultaneously, usually only a few control and limit the overall performance of the activity. Many scientists approach the understanding of physiological systems by studying the rate-limiting processes. First, scientists seek to define the metabolic or signaling pathway by identifying the components and sequences, then efforts focus on identifying the controlling factors. Imagine an assembly line that manufactures a commodity such as an automobile. Although there are many steps in the manufacturing process, assume that one step—installing the engine—is the slowest. If we want to increase production, it will do us little good to increase the speed of the other steps, such as assembling the chassis. Rather, we should focus our attention on speeding up the process of installing the engine. We might hire extra people to do the task, or use more machinery, or remove some impediment to the process so that workers can perform more rapidly. As we shall see, the body is controlled by and adjusts to exercise in a similar fashion.

In athletics, successful coaches are those who can identify the rate-limiting factor, sometimes called a weakness, and improve the individual's capacity to perform that process. Let us assume, for instance, we are coaching a novice wrestler who has been a successful competitive weight lifter. It makes no sense to emphasize strength training. Rather, we should emphasize technique development and other aspects of fitness, such as endurance. We would strive to maintain strength while concentrating on the performance-limiting factors. Similarly, we would be ill advised to have a 400-m runner do 100 miles of road running a week, because this type of fitness is of minimal use to this athlete and may even interfere with the enzymatic apparatus that facilitates the high rates of power output used in 400-m runs.

■ Maximal Oxygen Consumption ($\dot{V}_{O_2max}$) and Physical Fitness

The ability to supply energy for activities lasting more than 30 seconds depends on the consumption and use of oxygen (O_2). Because most physical activities in daily life, in athletics, and in physical

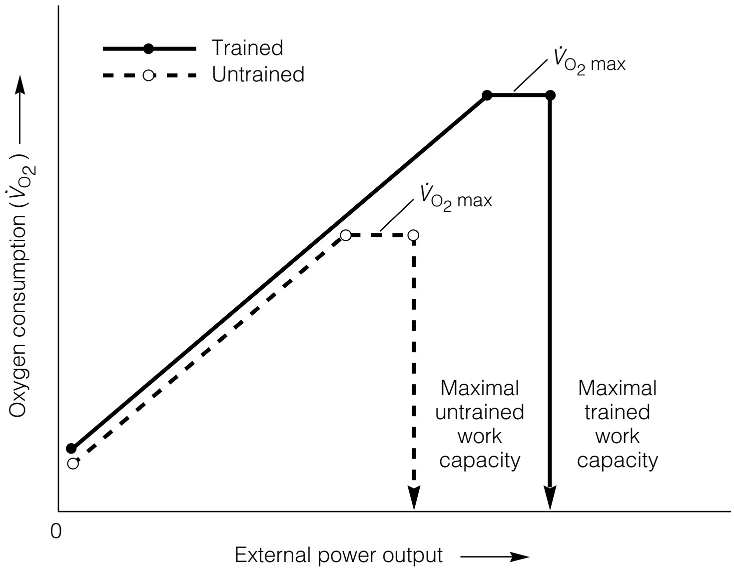

Figure 1-5 Relationship between oxygen consumption ($\dot{V}_{O_2}$) and external work rate (power output). In response to increments in power output, both trained and untrained individuals respond with an increase in $\dot{V}_{O_2}$. The greater ability of trained individuals to sustain a high power output is largely due to a greater maximal O_2 consumption ($\dot{V}_{O_2max}$).

medicine take more than 90 seconds, consumption of O_2 provides the energetic basis of our existence. The rate of consumption of a given volume of O_2 (abbreviated $\dot{V}_{O_2}$) increases as activities progress from rest to easy, to difficult, and finally to maximal work loads (Figure 1-5). The maximum rate at which an individual can consume oxygen ($\dot{V}_{O_2max}$) is an important determinant of the peak power output and the maximal sustained power output, or physical work capacity, of which an individual is capable. Moreover, an adequate good capacity to consume and utilize oxygen is essential for recovery from sprint (or burst) activity, as recovery is mainly an aerobic process.

As will be shown in later chapters, the capacity for $\dot{V}_{O_2max}$ depends on the capacity of the cardiovascular system. This realization that physical work capacity, $\dot{V}_{O_2max}$, and cardiovascular fitness are interrelated has resulted in a convergence of physical education (athletic performance) and medical (clinical) definitions of fitness. From the physical education–sports science perspective, cardiovascular function determines $\dot{V}_{O_2max}$, which in turn influences physical work capacity, or fitness (Figure 1-6). From the medicoclinical perspective, fitness involves, minimally, freedom from disease. Because cardiovascular disease is the greatest threat to the health of individuals in contemporary Western society, medical fitness is largely cardiovascular fitness. One of the major ways of determining cardiovascular fitness is measuring $\dot{V}_{O_2max}$. Therefore,

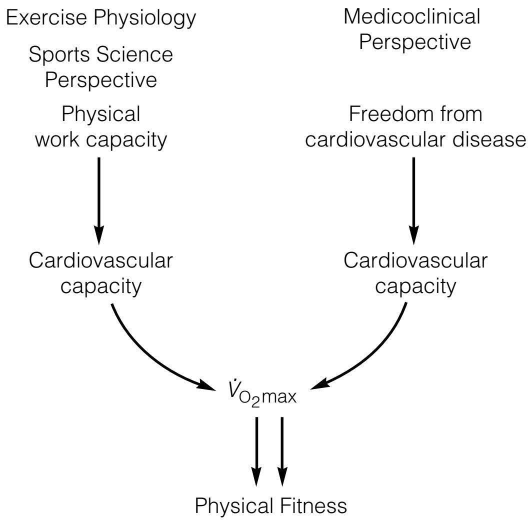

Figure 1-6 Because maximal oxygen consumption ($\dot{V}_{O_2max}$) depends on a high degree of cardiovascular health and because it is very important in aerobic (endurance) exercise, $\dot{V}_{O_2max}$ is becoming recognized as the most important index of physical fitness.

$\dot{V}_{O_2}$ is not only an important parameter of metabolism but also a good measure of fitness for life in contemporary society. In fact, $\dot{V}_{O_2\max}$ is so important from both the physical education–sports science and medicoclinical perspectives, it has emerged as the single most important criterion of physical fitness.

Factors Affecting the Performance of the Biological Machine

Although the body can be compared to a machine, it would be simplistic, and indeed dehumanizing, to leave it at that. Unlike a machine, the body can adapt to physical stresses and improve its function. Conversely, in the absence of appropriate stress, functional capacity deteriorates. In addition, whereas the functions of particular types of machines are set at the time of manufacture, the performances of human machines are quite variable. Performance capabilities change continuously throughout life according to several time-honored principles that account for many observed individual differences. These principles are examined next.

Stress and Response

Physiological systems respond to appropriate stimuli. Sometimes the stimulus is called "stress," and the response is called "strain." Repeated stresses on physical systems frequently lead to adaptations, resulting in an increase in functional capacity. Enlargement, or *hypertrophy,* in skeletal muscle occurs as a result of the stress of weight training. However, not all stresses are appropriate to enhance the functioning of physiological systems. For instance, although cigarette smoking is a stress, it does not improve lung function. Smoking is an example of an inappropriate stimulus.

Physiologically, the purpose of any training session is to stress the body so that adaptation results. Physical training is beneficial only as long as it forces the body to adapt to the stress of physical effort. If the stress is not sufficient to overload the body, then no adaptation occurs. If a stress is so great that it cannot be tolerated, then injury or overtraining result. The greatest improvements in performance occur when appropriate exercise stresses are introduced into an individual's training program.

Dr. Hans Selye has made scientists aware of the phenomenon of the stress-response-adaptation process, which he called the *general adaptation syndrome (GAS).* Selye described three stages involved in response to a stressor: alarm reaction, resistance development, and exhaustion. Each of these stages should be familiar to every physical educator, athlete, coach, physician, nurse, physical therapist, and other health professional who uses exercise to improve physical capacity.

Alarm Reaction The alarm reaction, the initial response to the stressor, involves the mobilization of systems and processes within the organism. During exercise, for example, the stress of running is supported by the strain of increasing oxygen transport through an augmentation of cardiac output and a redistribution of blood flow to active muscle. The body has a limited capacity to adjust to various stressors; thus, it must adapt its capacity so that the stressor is less of a threat to its homeostasis in the future.

Resistance Development The body improves its capacity or builds its reserves during the resistance stage of GAS. This stage represents the goal of physical conditioning. Unfortunately, the attainment of optimal physiological resistance (or *physical fitness,* the term more commonly used in athletics) does not occur in response to every random stressor. During physical training, for example, no training effect occurs if the stress is below a critical threshold. At the other extreme, if the stimulus cannot be tolerated, injury results.

The effectiveness of a stressor in creating an adaptive response is specific to an individual and relative to any given point in time and place. For example, running a 10-min mile may be exhausting to a sedentary 40-year-old man but would cause

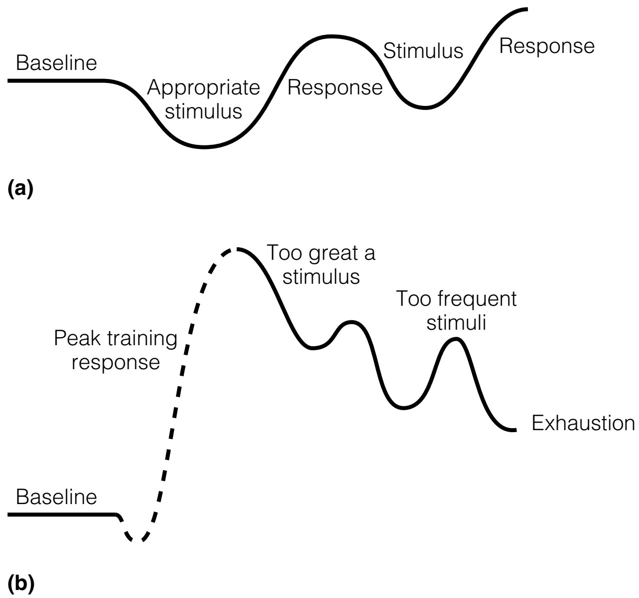

Figure 1-7 Illustration of the biological principle of stimulus and response, or the general adaptation syndrome, as applied to physical training. (a) Appropriate stimuli degrade the system slightly, but result in adaptive responses during recovery. Properly gauged and timed, training stimuli result in progressive improvements in physiological systems. (b) Application of too great a training stress and too frequent training can result in exhaustion of a physiological system.

essentially no adaptive response in a world-class runner. Likewise, a training run that is easily tolerated one day may be completely inappropriate following a prolonged illness. Environment can also introduce intra-individual variability in performance. An athlete will typically experience decreased performance in extreme heat and cold, at high altitudes, and in polluted air.

Exhaustion When stress becomes intolerable, the organism enters the third stage of GAS, exhaustion (or distress). The stress that results in exhaustion can be either acute or chronic. Examples of acute exhaustion include fractures, sprains, and strains. Chronic exhaustion (overtraining) is more subtle and includes stress fractures, emotional problems, and a variety of soft-tissue injuries. Again, the resistance development stage of GAS may require considerable time. It may therefore be inadvisable to elicit the alarm reaction frequently through severe training because the exhaustion stage of GAS may result. Periodization of training, involving training to a peak and then training at a reduced load before attempting a new peak, is discussed in Chapters 20 and 21 (Figure 1-7).

The Overload Principle

Application of an appropriate stressor is sometimes referred to as *overloading* the system. The principle of overload states that habitually overloading a system causes it to respond and adapt. Overload is a positive stressor that can be quantified according to load (intensity and duration), repetition, rest, and frequency.

Load refers to the intensity of the exercise stressor. In strength training, load refers to the amount of resistance; in running or swimming, it refers to speed. In general, the greater the load, the greater the fatigue and recovery time required.

Repetition refers to the number of times a load is administered. More favorable adaptation tends to occur (up to a point) when the load is administered more than once. In general, there is little agreement on the ideal number of repetitions in a given sport. The empirical maxims of sports training are in a constant state of flux as athletes become successful using overload combinations different from the norm. In middle-distance running and swimming, for example, interval training workouts have become extremely demanding as a result of the success of athletes who employed repetitions far in excess of those practiced only a few years ago.

Rest refers to the time interval between repetitions. Rest is vitally important for obtaining an adaptation and should be applied according to the nature of the desired physiological outcome. For example, a weight lifter who desires maximal strength is more concerned with load and less concerned with rest interval. However, too short a rest interval will impair the weight lifter's strength gain because inadequate recovery makes it impossible for him or her to exert maximal tension. Mountain climbers, by contrast, are more concerned with muscular endurance than peak strength, so they would use short rest intervals to maximize this fitness characteristic. Rest also refers to the interval between training sessions. Because some responses to stress are prolonged, adaptation to stress requires adequate rest and recovery. *Resting is a necessary part of training because adaptations occur during recovery.*

Frequency refers to the number of training sessions per week. In some sports, such as distance running, the tendency has been toward more frequent training sessions. Unfortunately, this often leads to increases in overuse injuries due to overtraining. Although more severe training regimens have resulted in improved performance in many sports, these workouts must be tempered with proper recovery periods or injury may result.

Specificity

It has repeatedly been observed that stressing a particular system or body part does little to affect other systems or body parts. For example, doing repeated biceps curls with the right arm may cause the right biceps to hypertrophy, but the right triceps or left biceps will be little affected. Any training program should reflect the desired adaptation. The closer the training routine is to the requirements of competition, the better the outcome will be.

Reversibility

In a way, the concept of reversibility is a restatement of the principle of overload and emphasizes that, whereas training may enhance performance, inactivity will lead to a performance decrement. For example, someone who built a robust circulatory system in college as a runner should expect little or no residual capacity at 40 years of age following 20 years of inactivity.

Individuality

We are all individuals and, whereas physiological responses to particular stimuli are generally predictable, one individual's precise response and adaptation to those stimuli are largely unpredictable and will vary from those of others. The same training regimen therefore may not benefit equally everyone who participates.

Development of the Field of Exercise Physiology

Many researchers have contributed the groundwork to the study of exercise physiology. Today, knowledge in this field is obtained from a wide range of studies. The testing of physical work capacities of athletes, laborers, soldiers, heart disease patients, and a variety of people to determine their metabolic responses to exercise remains an important area of interest. Questions relating to the caloric cost of exercise, the efficiency of exercise, and the fuels used to support the exercise are addressed. In addition to traditional methods of respiratory and blood metabolite determinations, newer techniques, including muscle sampling (biopsy), light and electron microscopy, enzymology, molecular biology, endocrinology, nuclear magnetic resonance (NMR), and radioactive and nonradioactive tracers have been developed that contribute to our understanding of the metabolic responses to exercise.

Along these lines, research has been carried out and is still under way to determine optimal training techniques for particular activities. The training regimens to improve such qualities as muscular strength and running endurance are vastly different.

When exercise tests are performed in a clinical setting, the term *stress test* is often used. Under controlled exercise conditions, cardiac and blood constituent responses are useful in determining the presence of underlying disease. Following an exercise stress test, an exercise prescription can be written to improve functional capacity.

Advances from the pioneer work of the late Roger Glaser and associates at Wright State University in Dayton, Ohio, in computerized control of paralyzed muscles now allow paraplegic and quadriplegic individuals to use their own muscle power to provide locomotion. (See Figure 1-4.) As with nonparalyzed muscles, repeated overload of paralyzed muscles—in this case by computer-controlled electrical stimulation—results in significant improvements in strength and endurance. Consequently, some muscles paralyzed for years can be trained and restored to near-normal strength. Together with appropriate orthopedic devices, these strengthened muscles allow paralyzed patients a degree of independence.

The effects of environment on physical performance have long been a concern in exercise physiology. Science and medicine, for example, have long been associated with mountaineering. Environmental studies reached their peak of interest, however, during preparations for the high-altitude Olympics held in Mexico in 1968, and new information was gained during studies on Pikes Peak and in a simulated ascent of Mt. Everest in the U.S. Army Research Institute of Environmental Medicine Decompression chamber (Reeves et al., 1990; Sutton et al., 1992; Young et al., 1992). Similarly, the Los Angeles Olympics stimulated research into the effects of heat and air pollution on human performance.

■ Pioneers and Leaders in Exercise Physiology

Exercise physiology has at times been in the forefront of the advances made in basic science. The greatest respiratory physiologist of all time was the eighteenth-century Frenchman Antoine L. Lavoisier, who used exercise to study physiology. Lavoisier contributed more to the understanding of metabolism and respiration than anyone will ever again have the opportunity to do (see Chapter 4). During the late nineteenth century in Germany, great strides were made in studying metabolism and nutrition under conditions of rest and exercise. Nathan Zuntz and his associates (including Schumburg and Geppert) were particularly important. Tables developed by Zuntz and Schumburg (1901) relating metabolic rate to O_2 consumption, CO_2 production, and amount of carbohydrate and fat used are essentially the same as those frequently referred to today by respiratory physiologists, exercise physiologists, and nutritionists. Work in exercise (Arbeits) physiology was also carried out in Germany, centered at the Max-Planck Institut für Arbeits physiologie. The Nazi regime and the events of World War II resulted in the emigration of many of these scientists to the United States, among them Ernst Simonsen (University of Minnesota) and Bruno Balke (University of Wisconsin).

In the early twentieth century, Francis G. Benedict and his associates, including Edward P. Cathcart and Henry M. Smith at the Carnegie Nutrition Laboratory in Boston, performed detailed studies on metabolism on people at rest and during steady-rate exercise. The precision, thoroughness, and insightful interpretation of results by the Carnegie Nutrition group is seldom matched today. The works of Benedict and Cathcart (1913) on the efficiency of the body during cycling exercise and similar work by Smith (1922) on the efficiency of walking should be required reading for all graduate students specializing in exercise physiology.

The giant in the field of exercise physiology, however, is English physiologist and Nobel laureate Archibald Vivian (A. V.) Hill. Hill's tremendous understanding of physiology was coupled with a likewise tremendous stamina for work and the technical ability to develop experimental devices. Throughout his career, Hill performed detailed studies on the energetics of muscles isolated from small animals. Moreover, he sought to relate the results of those detailed studies to the functioning, intact human. Hill and his associates (see Hill, Long, and Lupton, 1924) performed many studies on athletes and other individuals engaged in heavy exercise. In 1926, as a visiting lecturer at Cornell University, Hill studied acceleration in varsity sprinters. His influence was so great that he inspired a group of American scientists who later went on to help found the Harvard Fatigue Laboratory.

As recounted by David Bruce (D. B.) Dill (1967), the Harvard Fatigue Laboratory, established in the late 1920s at Harvard University to study exercise and environmental physiology, became a center for the study of applied physiology in the United States, attracting scientists from around the world. Included among visitors to the laboratory were Nobel laureate August Krogh of the University of Copenhagen (see below). In the field of exercise physiology, the laboratory is perhaps best known for the attempt by Margaria, Edwards, and Dill in the 1930s to understand metabolic responses to "non–steady-rate" exercise. As noted, earlier work in Germany and the United States had laid the foundation for understanding metabolic responses to continuous exercise of moderate intensity. The problems of understanding non–steady-rate metabolism, however, were—and remain—far more difficult. In tackling these problems, the Harvard group was carrying on in the tradition of A. V. Hill. The enormity of their task is revealed by the fact that these problems have still not been resolved (see Chapter 10).

When the laboratory was dissolved following World War II, its members dispersed, carrying with them their work and their commitment. Their dispersal led, perhaps, to a wider and more vigorous proliferation of work in exercise and environmental physiology than would have been possible had the laboratory remained the main site of research. Of particular note has been the work in the United States throughout the 1960s to 1980s of Sid Robinson at the University of Illinois and Steve Horvath at the University of California, Santa Barbara, and, in Italy, of Rudolfo Margaria at the University of Milan.

During the early twentieth century in Copenhagen, August Krogh established a laboratory for the study of zoological (comparative) physiology. Although Krogh's range of physiological interests was wide, he and his associates (Johannes L. Lindhard, Erik Hohwü-Christensen, Erling Asmussen, and Marius Neilsen) became known as exercise physiologists. When Krogh retired, Asmussen and Nielsen continued the work in Copenhagen; Hohwü-Christensen, in 1941, became professor at the Gymnastik-och Idrottshogkolan (GIH) in Stockholm. In 1960, Hohwü-Christensen was succeeded at the GIH by Per-Olaf (P.-O.) Åstrand.

The period from the late 1960s through the 1970s was an important time for exercise physiology. During this time, scientists began increasingly to apply the tools and techniques of biochemistry to the study of exercise physiology. In the United States, Philip Gollnick and John Holloszy, in large measure, invented the field of "exercise biochemistry." They and their associates developed the use of animal models to study basic metabolic and biochemical responses to exercise and exercise training. At about the same time in Sweden, Jonas Bergström and Eric Hultman first used the biopsy needle for studies of exercise physiology. This technical advance allowed lessons learned from animal experimentation to be extended to human subjects.

Also in the United States during this period, scientists at several Big-10 midwestern universities were playing essential roles in the development of the field. At the University of Wisconsin, Bruno Balke, whose contributions were many, was bringing to exercise physiology a European tradition, in which the disciplines and professions of medicine, exercise and environmental physiology, and physical education were all closely allied. At the University of Iowa, Charles M. Tipton's broad range of physiological interests were inspiring a generation of exercise physiologists, including Kenneth M. Baldwin, R. James Barnard, Frank Booth, and Ronald J. Terjung. Today, Baldwin (a coauthor of this work) and Booth are among the leaders in applying the techniques of molecular biology to the study of the effects of exercise and other stresses on cardiac and skeletal muscle structure and function. At the University of Michigan, John A. Faulkner's work in exercise and environmental physiology was instrumental in gaining acceptance for these areas as legitimate parts of basic physiology. Today, John Faulkner remains a driving force in muscle physiology and the physiology of aging. Faulkner's former students and postdoctoral fellows—and their students and fellows—have had a wide impact on the field. Included are George Brooks a coauthor of this text.

Meanwhile, discoveries were being made by exercise physiologists on the effects of activity on nerves and muscles. At UCLA, R. J. (Jim) Barnard, who had studied with Tipton at the University of Iowa, and V. R. (Reggie) Edgerton began a series of investigations that have shaped our views of how muscle function is controlled during acute and chronic exercise. The basic groundwork for their investigations was laid by neurophysiologists such as Elwood Henneman.

In the area of pressure flow and other cardiovascular responses to exercise, progress was also being made. Significant contributions were made by many scientists, especially Jere Mitchell (Dallas), Peter Raven (Fort Worth), Alf Holmgren (Stockholm), Larry Rowell (Seattle), Peter Wagner (San Diego), and John T. (Jack) Reeves (Colorado). At the University of Wisconsin, Madison, and the University of California, Davis, Jerry Dempsey and Marc Kaufman are making major strides in understanding the control of breathing during exercise. Today in Italy, the tradition of Rudolfo Margaria in studying exercise energetics and basic environmental physiology is being carried on by Pietro di Prampero (Udine) and Paolo Cerretelli (Milan).

In Scandinavia today, the rich tradition of studies in exercise physiology is continuing. Erik Richter is now professor in the University of Copenhagen Institute of Exercise and Sport Sciences. Michael Kjaer is professor and chief physician in the sports medicine unit at the Bispebjerg Hospital, and for 2003–5 Dr. Kjaer will be president of the European College of Sport Sciences. Also in Copenhagen, distinguished scientists such as Henrik Galbo, Bente Kiens, Bente Karlund-Pedersen, Bengt Saltin, and others are conducting important research in the field of fuel energy utilization in exercise. Together, they form the Copenhagen Muscle Research Center, which is preeminent in the fields of exercise and muscle physiology and exercise science and sports medicine.

In Canada, which may have the strongest research program per capita, interest in exercise physiology is flourishing. Whether or not they consider themselves exercise physiologists, Canadian researchers continue to make major contributions to the field. From Quebec (with François Peronnet, Jean-Pierre Despres, and Angelo Tremblay) to British Columbia (where the late Peter Hochachka worked and resided), there exist remarkable research and educational institutions. The province of Ontario, in particular, is noted for its numerous exercise physiologists, including Roy Shephard and Mladen Vranic (University of Toronto), David Hood, Enzo Cafarelli and Norman Gledhill (York), Arend Bonen, Lawrence Spriet, and Michael Lindinger (Guelph), Howard Green (Waterloo), and Norman Jones, Mark Tarnopolski, George Heigenhauser, and Duncan MacDougall (McMaster). Recently, Hood and Bonen have been recognized as Canada Research Chairs for their innovative and pioneering research.

Australia, too, is experiencing a resurgence of interest in exercise physiology. After years on the faculty at McMaster University in Ontario, John Sutton returned to the University of Sydney and instituted a center for sports medicine and basic and applied exercise physiology. Today, Maria Firatone Singh holds the John Sutton Chair of Exercise and Sports Science at the University of Sydney. In the United Kingdom, Clyde Williams directs the very active and distinguished program at Loughborough, where Ron Maughan has recently joined the faculty. In Scotland, several scientists are noted for their accomplishments; among them is Neil Spurway (Glasgow). In Cape Town, South Africa, Tim Noakes developed the Sports Sciences Institute, a research center that is making major contributions to both clinical sports medicine and the study of human energetics during exercise. In France, there is also a resurgence of effort; notable among French scientists are Jacques Mercier of Montpellier, who is known both as a scientist and a physician.

Interest in exercise physiology is evident in Asia as well. Though long unknown in the Western world because of language differences, programs in the study of exercise physiology are thriving. For example, in Japan, Mitsumasa Miyashita heads the sports medicine and exercise physiology group at the University of Tokyo, and Hideo Hatta has achieved worldwide prominence in the field of lactate transport protein expression. Hiroshi Nose is Professor of Sports Medicine at the Shinshu University School of Medicine, and Sadayoshi Taguchi is Professor of Human and Environmental Sciences at Kyoto University. Until his retirement, Chung Sung Tae headed a strong research program at Seoul National University in Korea. In China, efforts are directed more toward the application of exercise physiology to improving athletic performances.

Interest in exercise physiology is truly international, and the interest is growing in scope and sophistication, as is interest in the Olympics.

■ The Ever-Changing Fields of Exercise Physiology and Exercise and Sports Science in the United States and Elsewhere

In the previous section, a historical perspective and report on status of the fields of exercise physiology and exercise and sports science were articulated; now, we attempt to address the future of these fields. As a biological science, exercise physiology is constantly changing as new tools and technologies arise, and as overall sophistication and standards in the field develop. For example, the application of stable isotope technology has resulted in major revisions to Chapters 5–8 in the third and fourth editions of *Exercise Physiology.* Similarly, tools of molecular biology applied to the study of skeletal and cardiac muscle have resulted in significant changes in Chapters 17–19. Consequently, the chapters on training, particularly Chapter 21, have also changed in major ways. Reflective of the changes in science are corresponding changes in the organization and administration of higher education. The march of science, as well as the dynamics of change in institutions of higher education, parallel change in the fields of exercise physiology and exercise and sports science. For students in the field, some of the current trends are noted here.

Analysis of the previous section reveals a widespread interest in exercise physiology that has neither institutional nor national boundaries. Researchers who do sophisticated work and make major contributions to exercise physiology are scattered throughout the biological sciences at many different colleges, universities, and medical schools. An example of two highly regarded scientists in the field are Reggie Edgerton and Jim Barnard, who hold faculty positions at the Department of Physiological Sciences at UCLA. Another extraordinary example is the presence of Frank Booth, Harold Laughlin, and Ron Terjung in the Department of Biomedical Sciences, College of Veterinary Medicine, at the University of Missouri. However, departments of basic or clinical science rarely house more than a few faculty doing work related to exercise physiology. Consequently, most such departments at major research universities, so-called research 1 (R1) institutions, do not advertise exercise and sports science as a focus of the department.

There are probably several reasons for the minimal emphasis placed on exercise physiology and sports science at R1 institutions. One reason is that those institutions have diverse missions that do not include a health-and-fitness-related purpose. Another reason is that R1 institutions gauge their standings against each other from the National Research Council (NRC) ranking of departments. Because the NRC does not rank exercise science, kinesiology, physical education or any similarly titled department, the presence of departments of exercise science at institutions such as Harvard, Stanford, and Berkeley has waned; those types of institutions are unwilling to allocate resources to departments that have no hope of attaining an NRC ranking.

Fortunately, some R1 and many other institutions do see the need to support departments and programs of exercise and sports science. Therefore, leaders at several institutions have increased the prominence of programs in the field of exercise physiology and exercise and sports science. Because there is no definitive study or accepted set of objective criteria to rank departments of exercise science, no such effort will be undertaken here. However, the following provides some information on trends.

At the time of this writing, the University of Colorado at Boulder is perhaps preeminent in the field of exercise physiology due to the leadership of Russ Moore, who heads a department that includes Bob Mazzeo, Roger Enoka, Doug Seals, and Bill Byrnes. In terms of the research productivity, the faculty at Boulder remains consistently at the top. It has also developed an exceptional curriculum, and the department is large and oversubscribed with students.

A rising star in the field is the Department of Kinesiology at Kansas State University. There, a very active and productive group including Tim Musch, David Poole, Tom Barstow, Craig Harms, and Richard McAllister has been assembled. The University of Texas at Austin also needs to be mentioned as a site of excellence simply because of the accomplishments of John Ivy, Joe Starns, Roger Farrar, and Ed Coyle. Priscilla Clarkson, past president of the American College of Sports Medicine (ACSM), Patty Freedson, Barry Braun, and Jane Kent-Braun make the University of Massachusetts at Amherst another site of excellence in the field, and one that is noted for the leadership of its women. Faculty in the department of Exercise Science and Physical Education at Arizona State University, where Wayne Willis conducts elegant studies in the field of exercise biochemistry, will rightfully argue that their department is preeminent due to the breadth of their faculty expertise, which includes the renowned sports psychologist Dan Landers and George Stelmach, who is accomplished in motor learning.

Throughout the United States, the letters "USC" identify institutions of excellence in fields related to exercise physiology and kinesiology. At the University of Southern California, Casey Donovan and Lorraine Turcotte have made fundamental contributions to our understanding of the regulation of glucose and fatty acid metabolism. At the University of South Carolina, Russ Pate has not only advanced the field of exercise physiology, but he has also served as president of the American College of Sports Medicine. Pate's colleagues include Mark Davis, Larry Durstine, and until very recently, Barbara Ainsworth. Their department is unique in that it is housed in the School of Public Health, a position that reflects the important relationship between physical activity and health. Some of their many contributions are contained in the following section on the Surgeon General's Report on Physical Activity and Health. At the University of Florida, Scott Powers is co-director of the Center for Exercise Science; his area of expertise is the role of heat shock proteins (HSP) in the protection against oxidative damage. At Auburn University, L. Bruce Gladden is a leader in studies of lactate metabolism during exercise.

In conclusion, we reiterate the breadth of interest and the constancy of change in the fields of exercise physiology and exercise and sports science. Vision and leadership in these fields are important attributes, which combined with other factors will result in future progress. Already, the programs at the University of Colorado at Boulder and Kansas State University have been mentioned as distinguished sites of exercise physiology research. In the coming years, these programs will be rivaled by departments and programs at Oregon State University, where Tim White, a past president of the ACSM, was Provost and Executive Vice President before becoming President of the University of Idaho. In appointing Tammy Bray as Dean of the College of Health and Human Sciences, Melinda Manore as Chair of Nutrition and Food Management, and Christine Snow to the faculty of Exercise and Sports Science, Tim White built a program at OSU to rival any. Similarly, at Texas A & M, Bob Armstrong and Jack Wilmore are fashioning a faculty that may rival that at the University of Texas at Austin. Ultimately, there is every expectation that students beginning in the field today will emulate those mentioned here who have led the field to increasing levels of eminence.

■ Physical Activity and Health: A Report of the Surgeon General of the United States

The interim between publication of the second and third editions of *Exercise Physiology* was highlighted by publication of the Surgeon General's report titled "Physical Activity and Health" (http://www.cdc.gov/nccdphp/sgr/summary.htm). This report is a landmark in the history of muscle and exercise physiology and disciplines related to sports medicine, not only because it summarizes results of research from diverse fields, but also because the document serves as an articulation of public policy. The main message of this report is that Americans can substantially improve their health and quality of life by including moderate amounts of physical activity in their daily lives.

In 1994 the Office of the Surgeon General of the United States authorized the Centers for Disease Control and Prevention (CDC) to serve as the lead agency in preparing the first Surgeon General's report on physical activity and health. The CDC was joined in the effort by the President's Council on Physical Fitness and Sports (PCPFS), the Office of Public Health and Science, the Office of Disease Prevention at the National Institutes of Health (NIH), and several institutes from the NIH, including the National Heart, Lung, and Blood Institute; the National Institute of Child Health and Human Development; the National Institute of Diabetes and Digestive and Kidney Diseases; and the National Institute of Arthritis and Musculoskeletal and Skin Diseases. In addition, the CDC's efforts were buttressed by several nonfederal scholarly and professional organizations, including the American Alliance for Health, Physical Education, Recreation, and Dance (AAHPERD); the American College of Sports Medicine (ACSM); and the American Heart Association (AHA). Representatives of those organizations provided consultation throughout the development process.

The report is noteworthy in several respects. As previously stated, it recognized that physical activity is essential for the health and well-being of the general population, and it emphasized the importance of regular, moderate-intensity exercise as well as vigorous activity to achieve and maintain cardiorespiratory fitness. The report encourages people of all ages to include a minimum of 30 minutes of physical activity of moderate intensity (such as brisk walking) on most days. Further, the report was definite in recommending physical activity as a means to manage chronic diseases other than cardiovascular disease, such as diabetes, colon cancer, osteoarthritis, and osteoporosis. The Surgeon General's report noted also that in addition to promoting muscle strength and minimizing injury due to falls in the aged, regular exercise may be important in relieving symptoms of depression and anxiety, thereby improving mood and promoting a sense of well-being.

The interim between publication of the third and fourth editions of *Exercise Physiology* was marked by publication of the Institute of Medicine's report on dietary macronutrient consumption titled "Dietary Reference Intakes: Energy, Carbohydrate, Fiber, Fatty Acids, Cholesterol, Protein, and Amino Acids" (http://www.nap.edu/books/0309085373/html/). Contents of this report, generally referred to as the *Macronutrient Report,* are detailed in Chapter 28, but impact of this momentous report is detailed here.

In 2000 the NIH and Health Canada commissioned the National Academies of Science (NAS) to

> (1) review the scientific literature regarding macronutrients (proteins, amino acids, phospholipids, cholesterol, complex carbohydrates, simple sugars, dietary fiber, energy intake, and energy expenditure) to determine the roles, if any, they play in health; (2) review selected components of food that may influence the bioavailability of these compounds; (3) develop estimates of dietary intake of these compounds that are compatible with good nutrition throughout the life span and that may decrease the risk of chronic disease determine the tolerable upper intake levels for each compound.

Through its ancillary organizational units, specifically the Food and Nutrition Board of the Institute of Medicine (IOM), a panel of experts were convened to meet and author a technical report to provide guidance to health care professionals when making dietary recommendations. Because the possibilities for conflicts of interest and industrial espionage were rife, the NAS was commissioned to produce the *Report* under a federal statute dating from the U.S. Civil War; the NAS and its entities are immune from subpoena by all entities, including the U.S. Congress. The 2002 *Macronutrient Report* follows similar reports released in 1974, 1980, and 1989 in which distinguished panels of the Food and Nutrition Board labored to define *Recommended Daily Allowances* (RDAs) of dietary macronutrients.

Fundamental to work of the most recent panel authoring the *Macronutrient Report* was the decision to base daily dietary energy intake recommendations on energy expenditure. This approach became possible because of new *doubly labeled water* (DLW) isotope tracer technology so that energy expenditures of large numbers of people could be estimated with certainty. Those analyses revealed a wide range of energy expenditures by healthy adults, but the mean *physical activity level* (PAL) of those with stable body weights in the healthy range was 1.6, or 60% over basal. In terms of an activity that most people can relate to as well as accomplish, healthy people with favorable body weights and compositions are active equivalent to walking briskly an hour or more a day. *Hence, the equivalent of walking briskly for 60 min/day became the physical activity recommendation by the IOM Macronutrient panel.* The physical activity recommendation was only a small part of the overall list of recommendations in dietary macronutrient composition (Chapter 28), but for the first time dietary and physical activity recommendations were combined and presented in quantifiable terms. Hence, on a population basis, the recommendation for "a minimum of 30 minutes of physical activity of moderate intensity (such as brisk walking) on most, if not all, days of the week" in the 1996 Surgeon General's report has been more precisely determined and the recommendation is for activity equivalent to 60 min/day of brisk walking.

In short, like the 1996 Surgeon General's report on the health benefits of physical activity, the 2002 IOM *Macronutrient Report* combining physical activity and dietary recommendations represents a major departure from previous practices. It is testament to the growing recognition that prudent dietary and physical activity habits are important in promoting physical and mental health throughout the life cycle.

SUMMARY

Although the study of exercise physiology is in its infancy compared to other sciences such as chemistry and physics, it is bustling with activity. This area of research has a great deal of appeal because it concerns the limits of human potential. The results of these studies affect us all, whether we jog three times a week to improve our health, are concerned with the health of others, or are concerned with the training of world-class performers.

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