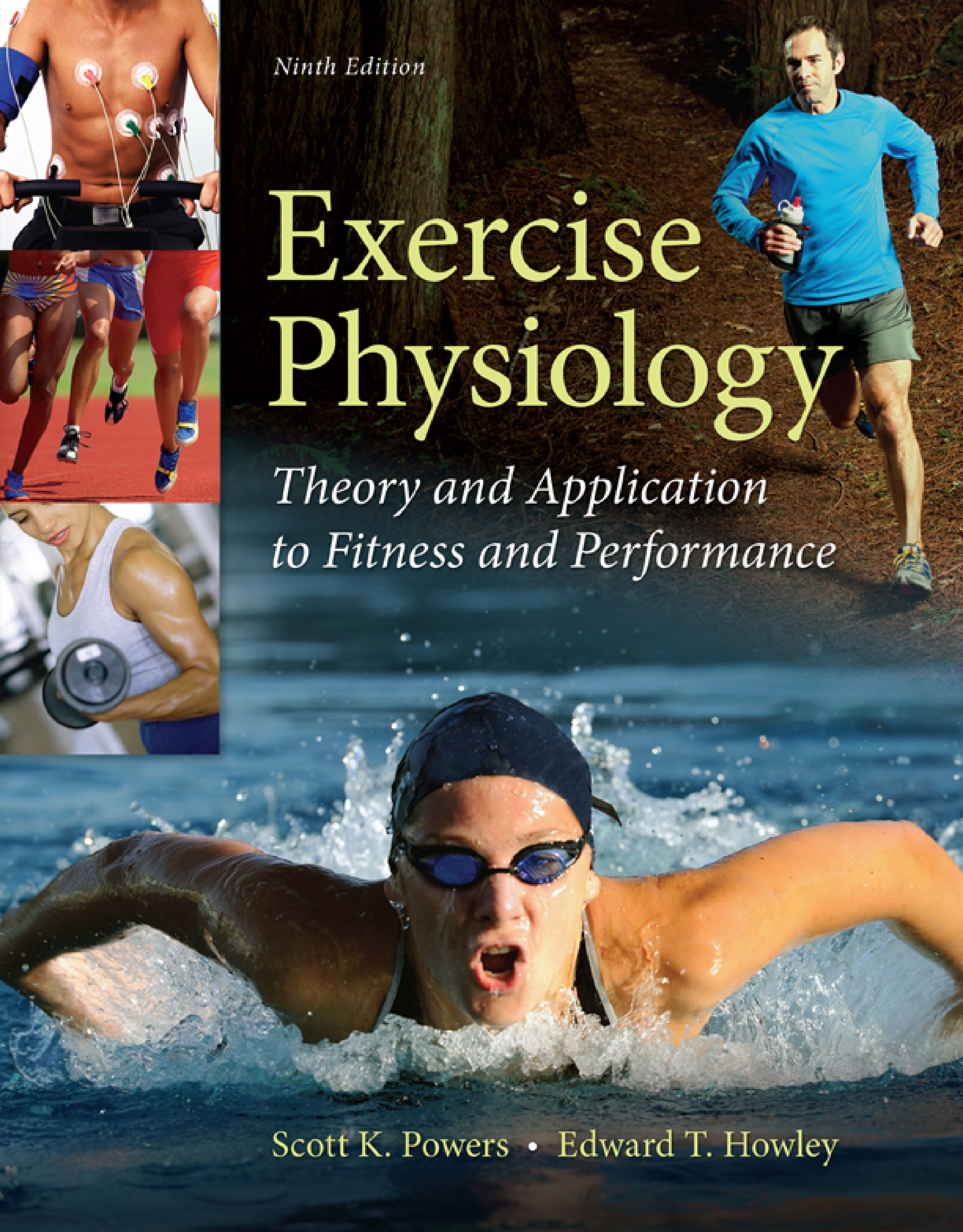


Ninth Edition

Exercise Physiology

Theory and Application to Fitness and Performance

Scott K. Powers • Edward T. Howley

EXERCISE PHYSIOLOGY

Theory and Application to Fitness and Performance

NINTH EDITION

Scott K. Powers
University of Florida

Edward T. Howley
University of Tennessee, Knoxville

McGraw Hill Education

EXERCISE PHYSIOLOGY: THEORY AND APPLICATION TO FITNESS AND PERFORMANCE,
NINTH EDITION

Published by McGraw-Hill Education, 2 Penn Plaza, New York, NY 10121.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 0 DOW/DOW 1 0 9 8 7 6 5 4

ISBN: 978-0-07-352353-8
MHID: 0-07-352353-4

Senior Vice President, Products & Markets: *Kurt L. Strand*
Vice President, General Manager, Products & Markets: *Michael Ryan*
Vice President, Content Design & Delivery: *Kimberly Meriwether David*
Managing Director: *Gina Boedeker*
Brand Manager: *Courtney Austermehle*
Director, Product Development: *Meghan Campbell*
Lead Product Developer: *Lisa Pinto*
Product Developer: *Jamie Daron*
Associate Marketing Manager: *Alexandra Schultz*
Director, Content Design & Delivery: *Terri Schiesl*
Full-Service Manager: *Faye Schilling*
Content Project Manager: *Mary Jane Lampe*
Buyer: *Jennifer Pickel*
Design: *Studio Montage*
Cover Images: Top: *techno tr/Getty Images, Butterfly stroke;* Left to right: *JUPITERIMAGES/Brand X/Alamy, Runners competing in race; Purestock/SuperStock, Young woman exercising with dumbbells; © Digital Vision/Punchstock, Male patient exercising while connected to heart rate monitoring equipment; Jacom Stephens/Getty Images, Man running along trail in Redwood Forest.*
Compositor: *MPS Limited*
Typeface: *10/12 ITC Novarese*
Printer: *R. R. Donnelley*

Library of Congress Cataloging-in-Publication Data

Powers, Scott K. (Scott Kline), 1950-
Exercise physiology : theory and application to fitness and performance /
Scott K. Powers, University of Florida, Edward T. Howley, University of
Tennessee, Knoxville. -- Ninth edition.
pages cm
Includes index.
ISBN 978-0-07-352353-8 (alk. paper)
1. Exercise--Physiological aspects. I. Howley, Edward T., 1943- II.
Title.
QP301.P64 2015
612'.044--dc23

2014026211

www.mhhe.com

Dedicated to Lou and Ann
for their love, patience, and support.

Brief Contents

SECTION 1

Physiology of Exercise 1

SECTION 2

Physiology of Health and Fitness 311

SECTION 3

Physiology of Performance 437

Appendices can be accessed at www.mhhe.com/powers9e:

Contents

Appendices can be accessed at www.mhhe.com/powers9e:

Preface

As with all previous editions, the ninth edition of *Exercise Physiology: Theory and Application to Fitness and Performance* is intended for students interested in exercise physiology, clinical exercise physiology, human performance, kinesiology/exercise science, physical therapy, and physical education. The overall objective of this text is to provide the student with an up-to-date understanding of the physiology of exercise. Moreover, the book contains numerous clinical applications including exercise tests to evaluate cardiorespiratory fitness and information on exercise training for improvements in health-related physical fitness and sports performance.

This book is intended for a one-semester, upper-level undergraduate or beginning graduate exercise physiology course. Clearly, the text contains more material than can be covered in a 15-week semester. This is by design. The book was written to be comprehensive and afford instructors the freedom to select the material that they consider to be the most important for the composition of their class. Furthermore, if desired, the book could be used in a two-semester sequence of exercise physiology courses (e.g., Exercise Physiology I and II) to cover the entire 25 chapters contained in the text.

NEW TO THIS EDITION

The ninth edition of our book has undergone *major* revisions and highlights the latest research in exercise physiology. Indeed, every chapter contains new and expanded discussions, new text boxes, new figures, updated references, and contemporary suggested readings.

New Topics and Updated Content

The content of this new edition has been markedly updated. Specifically, each chapter has been revised and updated to include new and amended box features, new illustrations, new research findings, and the inclusion of up-to-date references and suggested readings. The following list describes some of the significant changes that have made the ninth edition more complete and up-to-date:

- Contemporary section on careers in exercise science and kinesiology (Chap. 0).
- Revised section on estimating the energy cost of activities and a new discussion regarding the economy of running (Chap. 1).
- Expanded discussion on the regulation of homeostasis during exercise along with an up-to-date summary of the role that heat shock proteins play in cellular adaptation to stress (Chap. 2).
- New and improved illustrations added to enhance learning about the how and why of bioenergetics (Chap. 3).
- Updated information on the Cori cycle and fat-burning exercise (Chap. 4).
- Numerous new figures depicting hormone action along with the latest information on growth hormone, anabolic steroids, adipose tissue as an endocrine organ, and skeletal muscle as an endocrine organ (Chap. 5).
- Expanded details about how key cellular components of immunity protect against infection and the latest findings regarding the impact of exercise on the immune system (Chap. 6).
- Expanded discussion of muscle chemoreceptors and the role that they play in providing regulatory feedback to the nervous system during exercise (Chap. 7).
- New and improved figures depicting the steps leading to muscle contraction along

with new findings describing the molecular events that are responsible for muscle force production (Chap. 8).

- Improved illustrations and the latest research findings regarding the cardiovascular adjustments to exercise (Chap. 9).
- Up-to-date information regarding the control of breathing during exercise (Chap. 10).
- Expanded discussion of both cellular and extracellular buffer systems (Chap. 11).
- Addition of the latest research findings regarding temperature regulation during exercise (Chap. 12).
- Expanded information on exercise-induced changes in muscle fuel selection (Chap. 13).
- Increased focus on risk factors and chronic diseases, latest information on the risk factors for coronary artery disease, and expanded discussion on the impact of exercise and diet on inflammation and chronic disease (Chap. 14).
- Addition of the new Par-Q+, expanded presentation of the Canadian Aerobic Fitness Test, and revised discussion on the verification of $\dot{V}O_2$ max (Chap. 15).
- New section on importance of cardiorespiratory fitness relative to the risk of chronic disease, updated guidelines on resistance training and flexibility, and expanded discussion on the benefits of aerobic exercise versus resistance training (Chap. 16).
- Updated information on both type I and II diabetes, new guidelines for exercise and pregnancy, and the latest findings regarding exercise and older adults (Chap. 17).
- Fresh information on the glycemic index, new findings regarding obesity, and the latest recommendations from the American College of Cardiology on the importance of exercise and diet in weight loss (Chap. 18).
- Contemporary information regarding the role that free radicals play in muscle fatigue and a discussion of why Kenyans and Ethiopians win marathon races (Chap. 19).
- Latest information regarding laboratory testing of athletes (Chap. 20).
- New section on nutritional influences on training adaptations and addition of new information on concurrent strength and endurance training programs (Chap. 21).
- Recent research findings regarding the incidence of athletic amenorrhea and the female athlete triad (Chap. 22).
- Updates on the timing of protein intake to optimize protein synthesis during training and contemporary information on vitamin D supplementation (Chap. 23).
- Latest information regarding altitude training (i.e., live high/train low), updates on factors impacting heat illness, and updates on the impact of exercise in polluted environments (Chap. 24).
- New information on dietary supplements and athletic performance and a state-of-the-art discussion on new techniques for detecting doping in athletes (Chap. 25).

CREATE, BECAUSE CUSTOMIZATION MATTERS

Design your ideal course materials with McGraw-Hill's *Create:* www.mcgrawhillcreate.com. Rearrange or omit chapters, combine material from other sources, and/or upload your syllabus or any other content you have written to make the perfect resource for your students. Search thousands of leading McGraw-Hill textbooks to find the best content for your students, then arrange it to fit your teaching style. You can even personalize your book's appearance by selecting the cover and adding your name, school, and course information. When you order a *Create* book, you receive a complimentary review copy. Get a printed copy in three to five business days or an electronic copy (eComp) via e-mail in about an hour.

Register today at **www.mcgrawhillcreate.com,** and craft your course resources to match the way you teach.

INSTRUCTOR AND STUDENT ONLINE RESOURCES

www.mhhe.com/powers9e

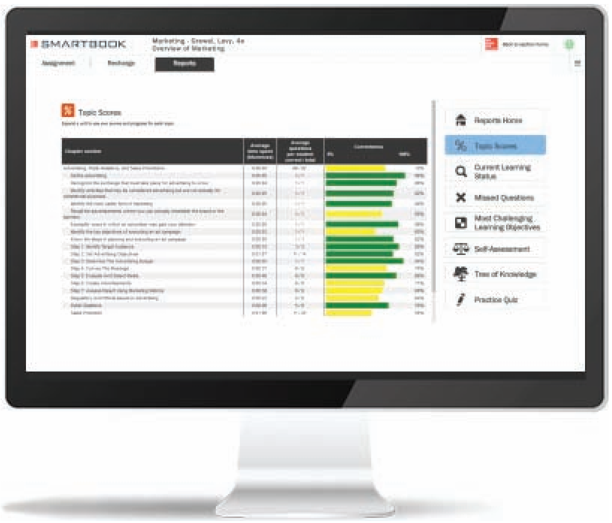
The Online Learning Center at **www.mhhe.com/powers9e** includes valuable teaching and learning tools, including assessment tools, classroom presentations, practice quizzes, and updated reference materials.

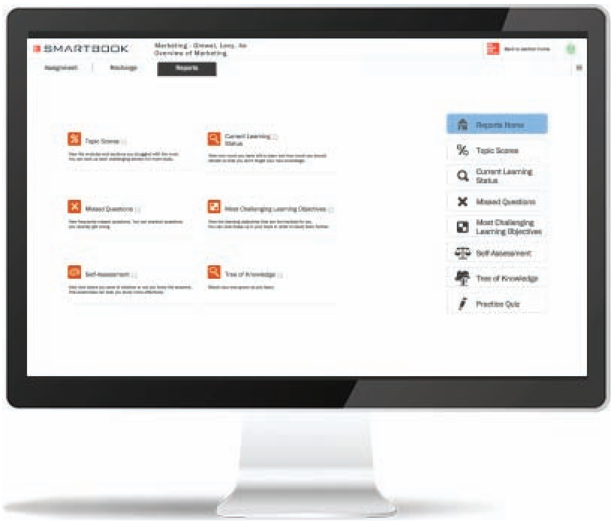
The 9th edition of *Exercise Physiology: Theory and Application to Fitness and Performance* is now available as a SmartBook™ – the first and only adaptive reading experience designed to change the way students read and learn:

SmartBook creates a personalized reading experience by highlighting the most impactful concepts a student needs to learn at that moment in time. As a student engages with SmartBook, the reading experience continuously adapts by highlighting content based on what the student knows and doesn't know. This ensures that the focus is on the content he or she needs to learn, while simultaneously promoting long-term retention of material. Use SmartBook's real-time reports to quickly identify the concepts that require more attention from individual students–or the entire class. The end result? Students are more engaged with course content, can better prioritize their time, and come to class ready to participate.

Key Student Benefits

- Engages the student in the reading process with a personalized reading experience that helps them study efficiently.
- SmartBook includes powerful reports that identify specific topics and learning objectives the student needs to study.
- Students can access SmartBook anytime via a computer and mobile devices.





Key Instructor Benefits

- Students will come to class better prepared because SmartBook personalizes the reading experience, allowing instructors to focus their valuable class time on higher level topics.
- Provides instructors with a comprehensive set of reports to help them quickly see how individual students are performing, identify class trends, and provide personalized feedback to students.

How does SmartBook work?

- ***Preview:*** Students start off by *Previewing* the content, where they are asked to browse the chapter content to get an idea of what concepts are covered.
- ***Read:*** Once they have *Previewed* the content, the student is prompted to *Read.* As he or she reads, SmartBook will introduce LearnSmart questions in order to identify what content the student knows and doesn't know.
- ***Practice:*** As the student answers the questions, SmartBook tracks their progress in order to determine when they are ready to *Practice.* As the students *Practice* in SmartBook, the program identifies what content they are most likely to forget and when.
- ***Recharge:*** That content is brought back for review during the *Recharge* process to ensure retention of the material

Speak to your McGraw-Hill Learning Technology Consultants today to find out more about adopting SmartBook for *Exercise Physiology: Theory and Application to Fitness and Performance, 9th edition!*

ACKNOWLEDGEMENTS

This text *Exercise Physiology: Theory and Application to Fitness and Performance* is not the effort of only two authors, but represents the contributions of hundreds of scientists from around the world. Although it is not possible to acknowledge every contributor to this work, we would like to recognize the following scientists who have greatly influenced our thinking, careers, and lives in general: Drs. Bruno Balke, Ronald Byrd, Jerome Dempsey, Stephen Dodd, H. V. Forster, B. D. Franks, Steven Horvath, Henry Montoye, Francis Nagle, and Hugh G. Welch.

Moreover, we would like to thank Kurt Sollanek, Aaron Morton, and Brian Parr for their assistance in providing suggestions for revisions to this book. Indeed, these individuals provided numerous contributions to the improvement of the ninth edition of this book. Finally, we would like to thank the following reviewers who provided helpful comments about the ninth edition of *Exercise Physiology:*

William Byrnes
University of Colorado at Boulder

Kathy Howe
Oregon State University

Jenny Johnson
American Military University

Gregory Martel
Coastal Carolina University

Erica Morley
Arizona State University

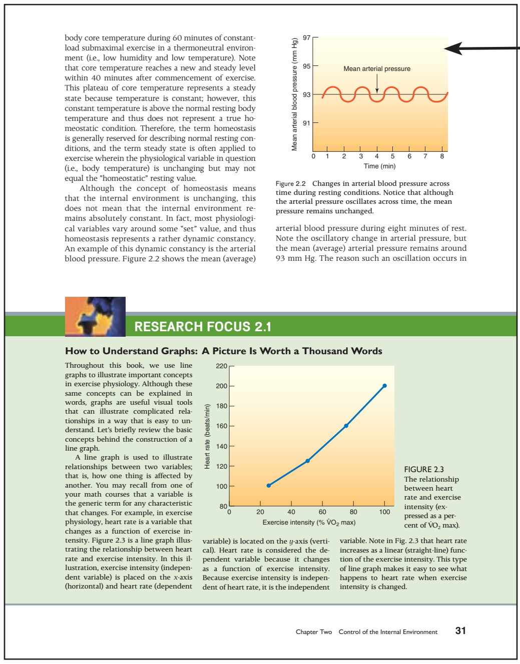
Allen C. Parcell
Brigham Young University

John Quindry
Auburn University

Brady Redus
University of Central Oklahoma

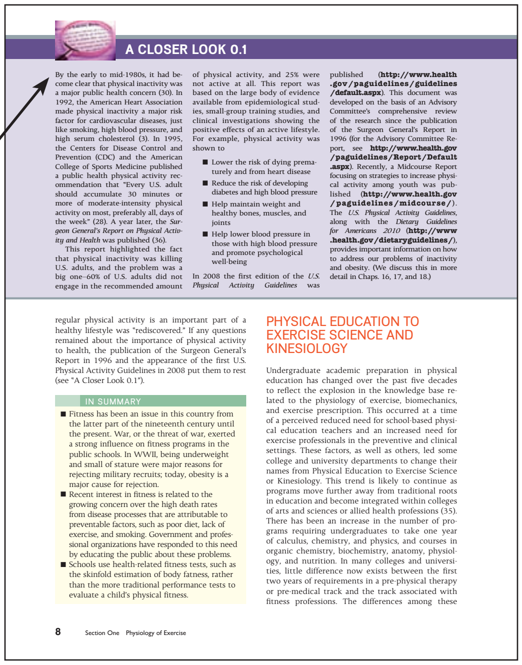
Ann M. Swartz
University of Wisconsin-Milwaukee

Engaging Presentation of Key Concepts Supported by the Latest Research



Research Focus

No matter what their career direction, students must learn how to read and think about the latest research. Research Focus presents new research and explains why it's relevant.



A Closer Look

A Closer Look offers an in-depth view of topics that are of special interest to students. This feature encourages students to dig deeper into key concepts.

Ask the Expert

This question-and-answer feature lets you find out what leading scientists have to say about topics such as the effect of space flight on skeletal muscle and the effect of exercise on bone health.

Practical Applications of Exercise Physiology

Clinical Applications

Learn how exercise physiology is used in the clinical setting.

CLINICAL APPLICATIONS 3.1

Diagnostic Value of Measuring Enzyme Activity in the Blood

When tissues become diseased, dead cells often break open and release their enzymes into the blood. Because many of these intracellular enzymes are not normally found in blood, the presence of a specific enzyme in blood provides important diagnostic information regarding the source of the medical problem. In practice, the diagnostic test proceeds as follows. A doctor obtains a blood sample from the patient and forwards the sample to a clinical laboratory for analysis. The laboratory then determines the activity of a specific enzyme in a test tube. The results of this test can often assist in making a diagnosis. For example, the finding that the blood sample contains high levels of the enzyme lactate dehydrogenase would suggest that the patient experienced a myocardial infarction (i.e., heart attack). Similarly, elevated blood levels of the enzyme creatine kinase would also indicate cardiac injury and would provide additional evidence that the patient suffered a heart attack. See Table 3.1 for additional examples of the diagnostic usage for specific enzymes found in blood.

TABLE 3.1 Examples of the Diagnostic Value of Enzymes Found in Blood

Enzyme	Diseases Associated with High Blood Levels of Enzyme
Lactate dehydrogenase (cardiac-specific isoform)	Myocardial infarction
Creatine kinase	Myocardial infarction, muscular dystrophy
Alkaline phosphatase	Carcinoma of bone, Paget's disease, obstructive jaundice
Amylase	Pancreatitis, perforated peptic ulcer
Aldolase	Muscular dystrophy

the enzyme's active site is specific to the shape of a particular substrate, which allows the two molecules (enzyme + substrate) to form a complex known as the enzyme-substrate complex. After the formation of the enzyme-substrate complex, the energy of activation needed for the reaction to occur is lowered, and the reaction is more easily brought to completion. This is followed by the dissociation of the enzyme and the product. The ability of an enzyme to work as a catalyst is not constant and can be modified by several factors; this will be discussed shortly.

Note that cellular enzymes can often play a key role in diagnosing specific illnesses. For example, when tissues are damaged due to a disease, dead cells within these tissues release enzymes into the blood. Many of these enzymes are not normally found in blood and therefore provide a clinical "clue" to diagnose the source of the illness. Details about the use of blood enzyme levels in the diagnosis of diseases are contained in Clinical Applications 3.1.

Classification of Enzymes In the early days of biochemistry, enzymes were named by the scientist who discovered them. Often, these names did not provide a clue as to the function of the enzyme. Therefore, to reduce confusion, an international committee developed a system that names the enzyme according to the type of chemical reaction it catalyzes. In this scheme, enzymes are provided a systematic name and a numerical identification. In addition, a shorter version of the systematic name, called the recommended name, was provided for everyday use. With the exception of some older enzyme names (e.g., pepsin, trysin, and rennin) all enzyme names end with the suffix "ase" and reflect both the job category of the enzyme and the reaction it catalyzes. For example, enzymes called kinases add a phosphate group (i.e., phosphorylate), a specific molecule. Other enzyme categories include dehydrogenases, which remove hydrogen atoms from their substrates, and oxidases, which catalyze oxidation-reduction reactions involving molecular oxygen. Enzymes called isomerases rearrange atoms within their substrate molecules to form structural isomers (i.e., molecules with the same molecular formula but with a different structural formula).

Chapter Three Bioenergetics 45

The Winning Edge

How do athletes find the "extra edge" that can make the difference between victory and defeat? These features explain the science behind a winning performance.

THE WINNING EDGE 3.1

Exercise Physiology Applied to Sports

Does Creatine Supplementation Improve Exercise Performance?
The depletion of phosphocreatine (PC) may limit exercise performance during short-term, high-intensity exercise (e.g., 100- to 200-meter dash) because the depletion of PC results in a reduction in the rate of ATP production by the ATP-PC system. Studies have shown that ingestion of large amounts of creatine monohydrate (20 grams/day) over a five-day period results in increased stores of muscle PC (2, 6, 14, 19, 26, 39). This creatine supplementation has been shown to improve performance in laboratory settings during short-duration (e.g., 30 seconds), high-intensity stationary cycling exercise (14, 19, 24, 26, 39). Note, however, that results on the influence of creatine supplementation on improving performance during short-duration running and swimming are not consistent (2, 14, 19, 26, 39).

Interestingly, studies also suggest that creatine supplementation in conjunction with resistance exercise training results in an enhanced physiologic adaptation to weight training (2, 5, 15, 23, 32, 39). Specifically, these studies indicate that creatine supplementation combined with resistance training promotes an increase in both dynamic muscular strength and fat-free mass. Nonetheless, whether creatine supplementation improves isokinetic or isometric muscular strength remains controversial (2).

Does oral creatine supplementation result in adverse physiological side effects and pose health risks? Unfortunately, a definitive answer to this question is not available. Although anecdotal reports indicate that creatine supplementation can be associated with negative side effects such as nausea, neurological dysfunction, minor gastrointestinal distress, and muscle cramping, these reports are not well documented (2, 7, 14, 20, 39). At present, due to limited data, a firm conclusion about the long-term health risks of creatine supplementation cannot be reached. However, current evidence suggests that creatine supplementation for up to eight weeks does not appear to produce major health risks, but the safety of more prolonged creatine supplementation has not been established.

An important issue related to the use of creatine and other dietary supplements is the possibility of contamination within the product; that is, the supplement product may contain other chemical compounds in addition to creatine (27). Indeed, this is an important safety issue in the "over-the-counter supplement" industry because a large study has reported a high level of variability in the purity of over-the-counter products (27). For more information on creatine and exercise performance, see Tarnopolsky (2010) in the Suggested Readings.

A CLOSER LOOK 3.2

Lactic Acid or Lactate?

In many textbooks, the terms "lactic acid" and "lactate" are used interchangeably. This is often confusing to students, who ask, "Are lactic acid and lactate the same molecule?" The answer is that lactic acid and lactate are related but are technically different molecules. Here's the explanation: The term *lactate* refers to the salt of lactic acid (Fig. 3.12) (4). You may recall from another science course that when acids dissociate and release hydrogen ions, the remaining molecule is called the *conjugate base* of the acid. It follows that lactate is the conjugate base of lactic acid. Because of the close relationship between lactic acid and lactate, many authors use these terms interchangeably (3). Remembering the relationship between lactic acid and lactate will reduce confusion when you read about these molecules in future chapters within this text.

Lactic acid ⇌ Lactate + H^+

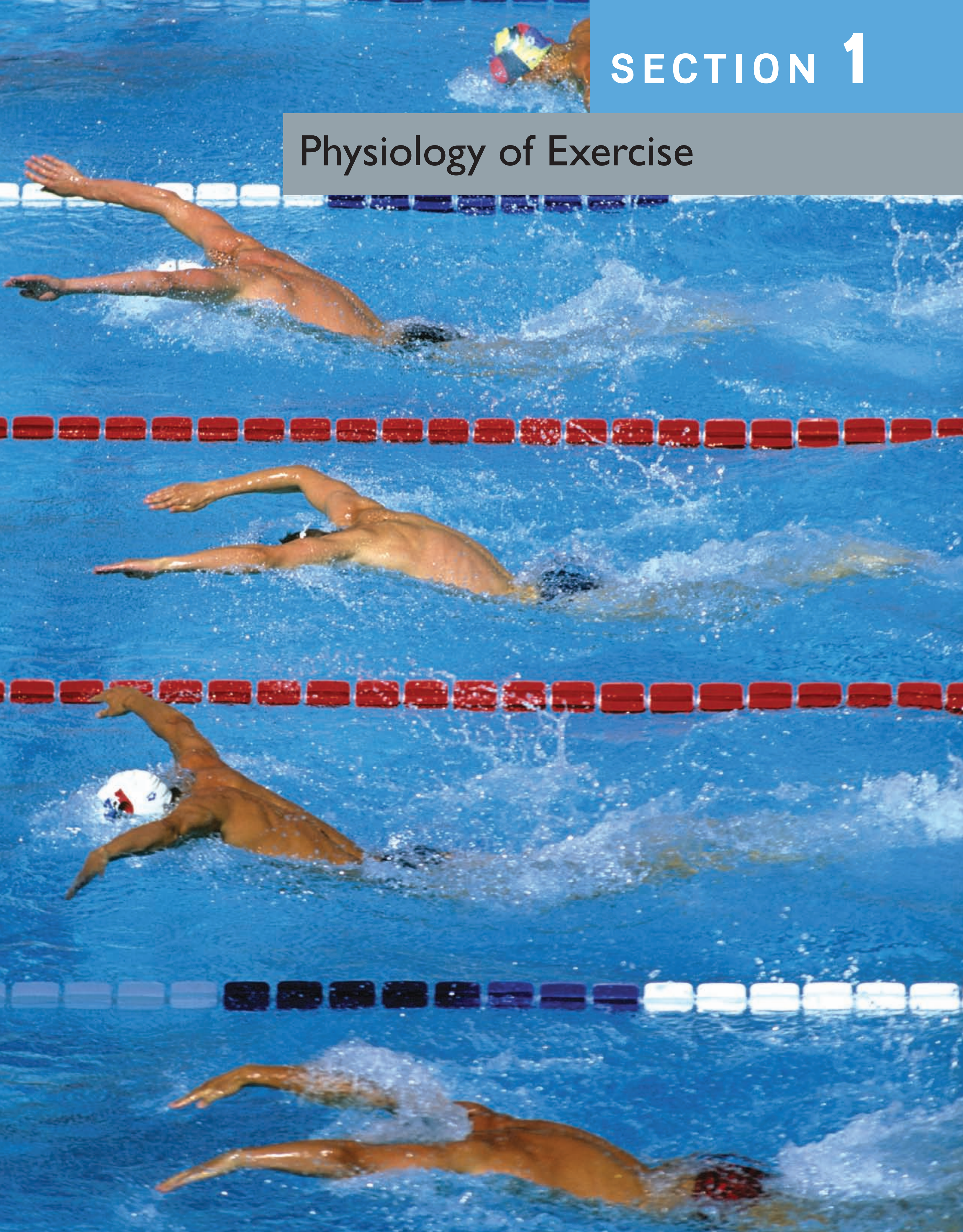
FIGURE 3.12 The ionization of lactic acid forms the conjugate base called lactate. At normal body pH, lactic acid will rapidly dissociate to form lactate.

breakdown of glucose or glycogen to form two molecules of pyruvate or **lactate** (Fig. 3.13). Simply stated, glycolysis is an anaerobic pathway used to transfer bond energy from glucose to rejoin P_i to ADP. This process involves a series of enzymatically catalyzed, coupled reactions. Glycolysis occurs in the sarcoplasm of the muscle cell and produces a net gain of two molecules of ATP and two molecules of pyruvate or lactate per glucose molecule (see A Closer Look 3.2).

50 Section One Physiology of Exercise

SECTION 1

Physiology of Exercise



0

Introduction to Exercise Physiology

Objectives

By studying this chapter, you should be able to do the following:

1. Describe the scope of exercise physiology as a branch of physiology.
2. Describe the influence of European scientists on the development of exercise physiology.
3. Name the three Nobel Prize winners whose research work involved muscle or muscular exercise.
4. Describe the role of the Harvard Fatigue Laboratory in the history of exercise physiology in the United States.
5. Describe factors influencing physical fitness in the United States over the past century.
6. List career options for students majoring in exercise science or kinesiology.

Outline

Does one need to have a "genetic gift" of speed to be a world-class runner, or is it all due to training? What happens to your heart rate when you take an exercise test that increases in intensity each minute? What changes occur in your muscles as a result of an endurance-training program that allows you to run at faster speeds over longer distances? What fuel–carbohydrate or fat–is most important when running a marathon? Research in exercise physiology provides answers to these and similar questions.

Physiology is the study of the function of tissues (e.g., muscle, nerve), organs (e.g., heart, lungs), and systems (e.g., cardiovascular). Exercise physiology extends this to evaluate the effect of a single bout of exercise (acute exercise) and repeated bouts of exercise (i.e., training programs) on these tissues, organs, and systems. In addition, the responses to acute exercise and training may be studied at high altitude or in extremes of heat and humidity to determine the impact of these environmental factors on our ability to respond and adapt to exercise. Finally, studies are conducted on young and old individuals, both healthy and those with disease, to understand the role of exercise in the prevention of or rehabilitation from various chronic diseases.

Consistent with this perspective, we go beyond simple statements of fact to show how information about the physiology of exercise is applied to the prevention of and rehabilitation from coronary heart disease, the performances of elite athletes, and the ability of a person to work in adverse environments such as high altitudes. The acceptance of terms such as *sports physiology, sports nutrition,* and *sports medicine* is evidence of the growth of interest in the application of physiology of exercise to real-world problems. Careers in athletic training, personal-fitness training, cardiac rehabilitation, and strength and conditioning, as well as the traditional fields of physical therapy and medicine, are of interest to students studying exercise physiology. We will expand on career opportunities later in the chapter.

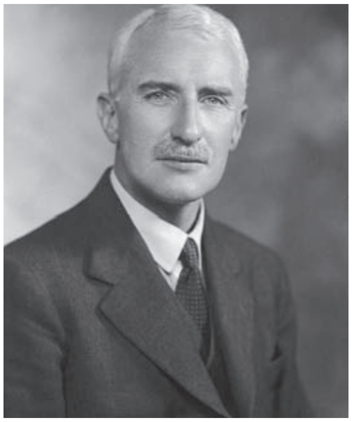
In this chapter we provide a brief history of exercise physiology to help you understand where we have been and where we are going. In addition, throughout the text a variety of scientists and clinicians are highlighted in a historical context as subject matter is presented (i.e., muscle, cardiovascular responses, altitude). We hope that by linking a person to a major accomplishment within the context of a chapter, history will come alive and be of interest to you.

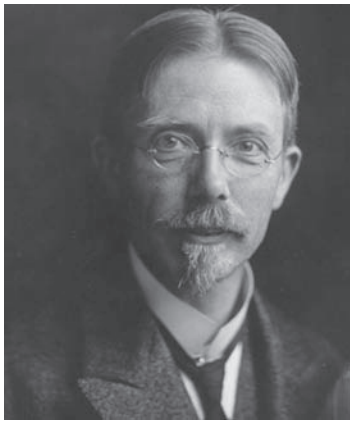
BRIEF HISTORY OF EXERCISE PHYSIOLOGY

The history of exercise physiology represents a global perspective involving scientists from many different countries. In this section we begin with the impact European scientists have had on the development of exercise physiology. We then describe the role of the Harvard Fatigue Laboratory in the growth of exercise physiology in this country.

European Heritage

A good starting place to discuss the history of exercise physiology in the United States is in Europe. Three scientists, A. V. Hill of Britain, August Krogh of Denmark, and Otto Meyerhof of Germany, received Nobel Prizes for research on muscle or muscular exercise (12). Hill and Meyerhof shared the Nobel Prize in Physiology or Medicine in 1922. Hill was recognized for his precise measurements of heat production during muscle contraction and recovery, and Meyerhof for his discovery of the relationship between the consumption of oxygen and the measurement of lactic acid in muscle. Hill was trained as a mathematician before becoming interested in physiology. In addition to his work cited for the Nobel Prize, his studies on humans led to the development of a framework around which we understand the physiological factors related to distance-running performance (6) (see Chap. 19).


A


B


C

A. Archibald V. Hill, B. August Krogh, C. Otto F. Meyerhof

Although Krogh received the Nobel Prize for his research on the function of capillary circulation, he had a major impact on numerous areas of investigation. Furthermore, like many productive investigators, his influence was due not only to his own work, but to that of his students and colleagues as well. Krogh's collaboration with Johannes Lindhard resulted in classic studies dealing with carbohydrate and fat metabolism during exercise, and how the cardiovascular and respiratory systems' responses are controlled during exercise (4). Three of Krogh's students, Erling Asmussen, Erik Hohwü-Christensen, and Marius Nielsen (called the three musketeers by Krogh), had a major impact on exercise physiology research throughout the middle of the twentieth century. These investigators, in turn, trained a number of outstanding physiologists, several of whom you will meet throughout this text. The August Krogh Institute in Denmark contains some of the most prominent exercise physiology laboratories in the world. Marie Krogh, his wife, was a noted scientist in her own right and was recognized for her innovative work on measuring the diffusing capacity of the lung. We recommend the biography of the Kroghs written by their daughter, Bodil Schmidt-Nielsen (see Suggested Readings), for those interested in the history of exercise physiology.

Several other European scientists must also be mentioned, not only because of their contributions to the exercise physiology, but also because their names are commonly used in a discussion of exercise physiology. J. S. Haldane did some of the original work on the role of CO_2 in the control of breathing. Haldane also developed the respiratory gas analyzer that bears his name (15). C. G. Douglas did pioneering work with Haldane in the role of O_2 and lactic acid in the control of breathing during exercise, including some work conducted at various altitudes. The canvas-and-rubber gas collection bag used for many years in exercise physiology laboratories around the world carries Douglas's name. A contemporary of Douglas, Christian Bohr of Denmark, did the classic work on how O_2 binds to hemoglobin. The "shift" in the oxygen-hemoglobin dissociation curve due to the addition of CO_2 bears his name (see Chap. 10). Interestingly, it was Krogh who did the actual experiments that enabled Bohr to describe his famous "shift." (4, 15).

The "three musketeers": From left to right: Erling Asmussen, Erik Hohwü-Christensen, and Marius Nielsen

IN SUMMARY

- A. V. Hill, August Krogh, and Otto Meyerhof received the Nobel Prize for work related to muscle or muscular exercise.
- Numerous European scientists have had a major impact on the field of exercise physiology.

Harvard Fatigue Laboratory

A focal point in the history of exercise physiology in the United States is the Harvard Fatigue Laboratory. Professor L. J. Henderson organized the laboratory within the Business School to conduct physiological research on industrial hazards. Dr. David Bruce Dill was the research director from the time the laboratory opened in 1927 until it closed in 1947 (18). Table 0.1 shows that the scientists conducted research in numerous areas, in the laboratory and in the field, and the results of those early studies have been supported by recent investigations. Dill's classic text, *Life, Heat, and Altitude* (14), is recommended reading for any student of exercise and environmental physiology. Much of the careful and precise work of the laboratory was conducted using the now-classic Haldane analyzer for respiratory gas analysis and the van Slyke apparatus for blood-gas analysis. The advent of computer-controlled equipment in the 1980s has made data collection easier but has not improved on the accuracy of measurement (see Figure 0.1).

David Bruce Dill

TABLE 0.1 Active Research Areas in the Harvard Fatigue Laboratory

Metabolism
Maximal oxygen uptake
Oxygen debt
Carbohydrate and fat metabolism during long-term work
Environmental physiology
Altitude
Dry and moist heat
Cold
Clinical physiology
Gout
Schizophrenia
Diabetes
Aging
Basal metabolic rate
Maximal oxygen uptake
Maximal heart rate
Blood
Acid-base balance
O_2 saturation: role of PO_2, PCO_2, and carbon monoxide
Nutrition assessment techniques
Vitamins
Foods
Physical fitness
Harvard Step Test

The Harvard Fatigue Laboratory attracted doctoral students as well as scientists from other countries. Many of the alumni from the laboratory are recognized in their own right for excellence in research in the physiology of exercise. Two doctoral students, Steven Horvath and Sid Robinson, went on to distinguished careers at the Institute of Environmental Stress in Santa Barbara and Indiana University, respectively.

Foreign "Fellows" included the "three musketeers" mentioned in the previous section (E. Asmussen, E. Hohwü-Christensen, and M. Nielsen) and the Nobel Prize winner August Krogh. These scientists brought new ideas and technology to the lab, participated in laboratory and field studies with other staff members, and published some of the most important work in the exercise physiology between 1930 and 1980. Rudolpho Margaria, from Italy, went on to extend his classic work on oxygen debt and described the energetics of locomotion. Peter F. Scholander, from Norway, gave us his chemical gas analyzer that is a primary method of calibrating tank gas used to standardize electronic gas analyzers (18).

In summary, under the leadership of Dr. D. B. Dill, the Harvard Fatigue Laboratory became a model for research investigations into exercise and environmental physiology, especially as it relates to humans. When the laboratory closed and the staff dispersed, the ideas, techniques, and approaches to scientific inquiry were distributed throughout the world, and with them, Dill's influence in the area of environmental and exercise physiology. Dr. Dill continued his research outside Boulder City, Nevada, into the 1980s. He died in 1986 at the age of 93.

Progress toward understanding any issue in exercise physiology transcends time, national origin, and scientific training. Solutions to difficult questions require the interaction of scientists from diverse disciplines and professions such as physiology, biochemistry, molecular biology, and medicine. We recommend *Exercise Physiology–People and Ideas* (see the Suggested Readings) to further your understanding of important historical connections. In this book, internationally known scientists provide a historical treatment of a number of important issues in exercise physiology, with an emphasis on the cross-continent flow of energy and ideas. We highlight several scientists and clinicians with our "Ask the Expert" boxes throughout the text, both to introduce them to you

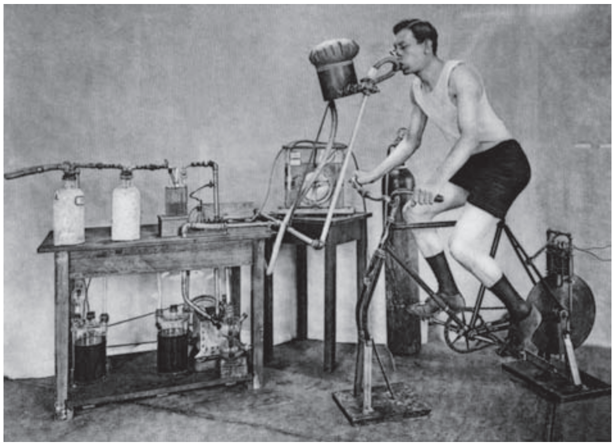
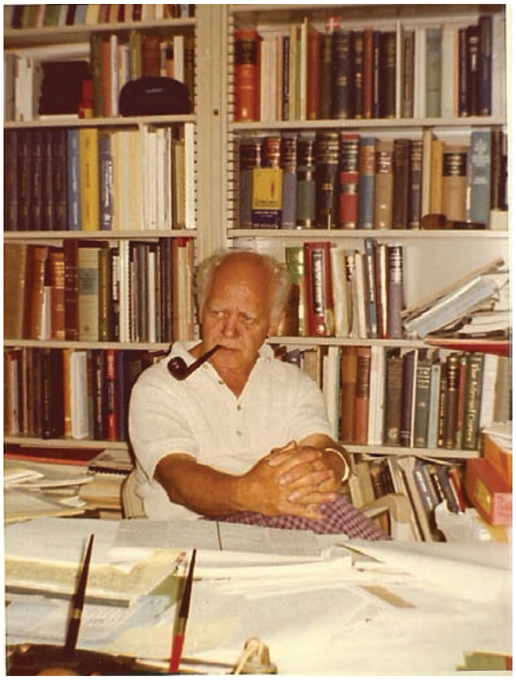
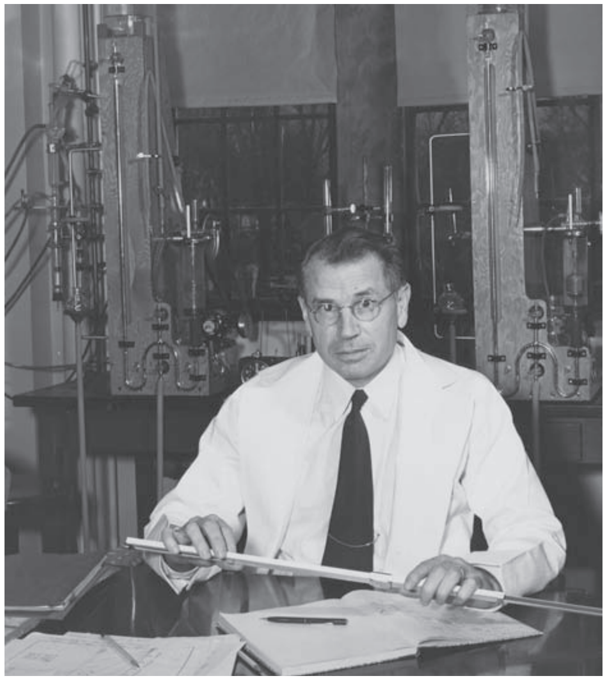


Figure 0.1 Comparison of old and new technology used to measure oxygen consumption and carbon dioxide production during exercise. (*Left:* The Carnegie Institute of Washington, D.C.; *Right:* COSMED.)


A

B

A. Steven Horvath, B. Sid Robinson.

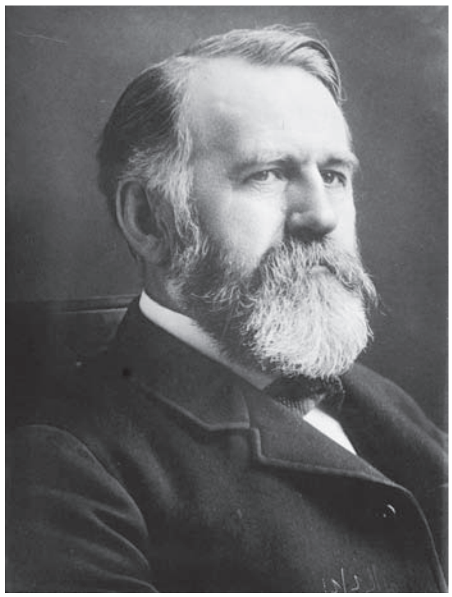
and for them to share their current ideas. In addition, "A Look Back–Important People in Science," is used to recognize well-known scientists who have influenced our understanding of exercise physiology. In this context you will get to know those who have gone before and those who are currently leading the charge.

IN SUMMARY

- The Harvard Fatigue Laboratory was a focal point in the development of exercise physiology in the United States. Dr. D. B. Dill directed the laboratory from its opening in 1927 until its closing in 1947. The body of research in exercise and environmental physiology produced by the scientists in that laboratory formed the foundation for new ideas and experimental methods that still influence us today.

PHYSIOLOGY, PHYSICAL FITNESS, AND HEALTH

Physical fitness is a popular topic today, and its popularity has been a major factor in motivating college students to pursue careers in physical education, exercise physiology, health education, nutrition, physical therapy, and medicine. In 1980, the Public Health Service listed "physical fitness and exercise" as one of 15 areas of concern related to improving the country's overall health (30). This was far from a new idea. Similar interests and concerns about physical fitness existed in this country more than 100 years ago. Between the Civil War and the First World War (WWI), physical education was primarily concerned with the development and maintenance of fitness, and many of the leaders in physical education were trained in medicine (13) (p. 5). For example, Dr. Dudley Sargent, hired by Harvard University in 1879, set up a physical training program with individual exercise prescriptions to improve a person's structure and function to achieve "that prime physical condition called fitness–fitness for work, fitness for play, fitness for anything a man may be called upon to do" (33) (p. 297).



Dudley Sargent

Sargent was clearly ahead of his time in promoting health-related fitness. Later, war became a primary force driving this country's interest in physical fitness. Concerns about health and fitness were raised during WWI and WWII when large numbers of draftees failed the induction exams due to mental and physical defects (17) (p. 407). These concerns influenced the type of physical education programs in the schools during these years, making them resemble premilitary training programs (37) (p. 484). Interestingly, whereas stunted growth and being underweight were major reasons for rejecting military recruits in WWII, obesity is the major cause for rejecting recruits today (see "Still Too Fat to Fight" at **http://www.missionreadiness.org/2012/still-too-fat-to-fight/**).

The present interest in physical activity and health was stimulated in the early 1950s by two major findings: (1) autopsies of young soldiers killed during the Korean War showed that significant coronary artery disease had already developed, and (2) Hans Kraus showed that American children performed poorly on a minimal muscular fitness test compared to European children (37) (p. 516). Due to the latter finding, President Eisenhower initiated a conference in 1955 that resulted in the formation of the President's Council on Youth Fitness. The American Association for Health, Physical Education, and Recreation (AAHPER) supported these activities and in 1957 developed the AAHPER Youth Fitness Test with national norms to be used in physical education programs throughout the country. Before he was inaugurated, President Kennedy expressed his concerns about the nation's fitness in an article published in *Sports Illustrated*, called "The Soft American" (22):

> For the physical vigor of our citizens is one of America's most precious resources. If we waste and neglect this resource, if we allow it to dwindle and grow soft, then we will destroy much of our ability to meet the great and vital challenges which confront our people. We will be unable to realize our full potential as a nation.

During Kennedy's term, the council's name was changed to the "President's Council on Physical Fitness" to highlight the concern for fitness. The name was changed again in the Nixon administration to the "President's Council on Physical Fitness and Sports," which supported fitness not only in schools, but also in business, industry, and for the general public. The name was most recently changed by President Obama to the "President's Council on Fitness, Sports, & Nutrition" to focus more attention on the obesity epidemic (see **www.fitness.gov**). Items in the Youth Fitness Test were changed over the years, and in 1980 the American Alliance for Health, Physical Education, Recreation, and Dance (AAHPERD) published a separate *Health-Related Physical Fitness Test Manual* (1) to distinguish between "performance testing" (e.g., 50-yard dash) and "fitness testing" (e.g., skinfold thickness). This health-related test battery is consistent with the direction of lifetime fitness programs, being concerned with obesity, cardiorespiratory fitness, and low-back function. A parallel fitness test, FitnessGram, was developed by The Cooper Institute in 1982, including software to support the scoring and printing of reports (see **http://www.fitnessgram.net/home/**). For readers interested in the history of fitness testing in schools, we recommend Morrow et al.'s review in the Suggested Readings.

Paralleling this interest in the physical fitness of youth was the rising concern about the death rate from coronary heart disease in the middle-aged American male population. Epidemiological studies of the health status of the population underscored the fact that degenerative diseases related to poor health habits (e.g., high-fat diet, smoking, inactivity) were responsible for more deaths than the classic infectious and contagious diseases. In 1966, a major symposium highlighted the need for more research in the area of physical activity and health (31). In the 1970s, there was an increase in the use of exercise tests to diagnose heart disease and to aid in the prescription of exercise programs to improve cardiovascular health. Large corporations developed "executive" fitness programs to improve the health status of that high-risk group. While most Americans are now familiar with such programs, and some students of exercise physiology seek careers in "corporate fitness," such programs are not new. The photo in Figure 0.2, taken from the 1923 edition of McKenzie's *Exercise in Education and Medicine* (25), shows a group of businessmen in costume doing dance exercises. In short, the idea that

Figure 0.2 A group of businessmen in a dancing class under the direction of Oliver E. Hebbert.

A CLOSER LOOK 0.1

By the early to mid-1980s, it had become clear that physical inactivity was a major public health concern (30). In 1992, the American Heart Association made physical inactivity a major risk factor for cardiovascular diseases, just like smoking, high blood pressure, and high serum cholesterol (3). In 1995, the Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine published a public health physical activity recommendation that "Every U.S. adult should accumulate 30 minutes or more of moderate-intensity physical activity on most, preferably all, days of the week" (28). A year later, the *Surgeon General's Report on Physical Activity and Health* was published (36).

This report highlighted the fact that physical inactivity was killing U.S. adults, and the problem was a big one–60% of U.S. adults did not engage in the recommended amount of physical activity, and 25% were not active at all. This report was based on the large body of evidence available from epidemiological studies, small-group training studies, and clinical investigations showing the positive effects of an active lifestyle. For example, physical activity was shown to

- Lower the risk of dying prematurely and from heart disease
- Reduce the risk of developing diabetes and high blood pressure
- Help maintain weight and healthy bones, muscles, and joints
- Help lower blood pressure in those with high blood pressure and promote psychological well-being

In 2008 the first edition of the *U.S. Physical Activity Guidelines* was published (**http://www.health.gov/paguidelines/guidelines/default.aspx**). This document was developed on the basis of an Advisory Committee's comprehensive review of the research since the publication of the Surgeon General's Report in 1996 (for the Advisory Committee Report, see **http://www.health.gov/paguidelines/Report/Default.aspx**). Recently, a Midcourse Report focusing on strategies to increase physical activity among youth was published (**http://www.health.gov/paguidelines/midcourse/**). The *U.S. Physical Activity Guidelines*, along with the *Dietary Guidelines for Americans 2010* (**http://www.health.gov/dietaryguidelines/**), provides important information on how to address our problems of inactivity and obesity. (We discuss this in more detail in Chaps. 16, 17, and 18.)

regular physical activity is an important part of a healthy lifestyle was "rediscovered." If any questions remained about the importance of physical activity to health, the publication of the Surgeon General's Report in 1996 and the appearance of the first U.S. Physical Activity Guidelines in 2008 put them to rest (see "A Closer Look 0.1").

IN SUMMARY

- Fitness has been an issue in this country from the latter part of the nineteenth century until the present. War, or the threat of war, exerted a strong influence on fitness programs in the public schools. In WWII, being underweight and small of stature were major reasons for rejecting military recruits; today, obesity is a major cause for rejection.
- Recent interest in fitness is related to the growing concern over the high death rates from disease processes that are attributable to preventable factors, such as poor diet, lack of exercise, and smoking. Government and professional organizations have responded to this need by educating the public about these problems.
- Schools use health-related fitness tests, such as the skinfold estimation of body fatness, rather than the more traditional performance tests to evaluate a child's physical fitness.

PHYSICAL EDUCATION TO EXERCISE SCIENCE AND KINESIOLOGY

Undergraduate academic preparation in physical education has changed over the past five decades to reflect the explosion in the knowledge base related to the physiology of exercise, biomechanics, and exercise prescription. This occurred at a time of a perceived reduced need for school-based physical education teachers and an increased need for exercise professionals in the preventive and clinical settings. These factors, as well as others, led some college and university departments to change their names from Physical Education to Exercise Science or Kinesiology. This trend is likely to continue as programs move further away from traditional roots in education and become integrated within colleges of arts and sciences or allied health professions (35). There has been an increase in the number of programs requiring undergraduates to take one year of calculus, chemistry, and physics, and courses in organic chemistry, biochemistry, anatomy, physiology, and nutrition. In many colleges and universities, little difference now exists between the first two years of requirements in a pre-physical therapy or pre-medical track and the track associated with fitness professions. The differences among these tracks lie in the "application" courses that follow. Biomechanics, physiology of exercise, fitness assessment, exercise prescription, strength and conditioning, and so on belong to the physical education/exercise science track. However, it must again be pointed out that this new trend is but another example of a rediscovery of old roots rather than a revolutionary change. Kroll describes two 4-year professional physical education programs in the 1890s, one at Stanford and the other at Harvard, that were the forerunners of today's programs (23) (pp. 51–64). They included the detailed scientific work and application courses with clear prerequisites cited. Finally, considerable time was allotted for laboratory work. No doubt, Lagrange's 1890 text, *Physiology of Bodily Exercise* (24), served as an important reference source for these students. The expectations and goals of those programs were almost identical to those specified for current exercise physiology undergraduate tracks. In fact, one of the aims of the Harvard program was to allow a student to pursue the study of medicine after completing two years of study (23) (p. 61).

GRADUATE STUDY AND RESEARCH IN THE PHYSIOLOGY OF EXERCISE

While the Harvard Fatigue Laboratory was closing in 1947, the country was on the verge of a tremendous expansion in the number of universities offering graduate study and research opportunities in exercise physiology. A 1950 survey showed that only 16 colleges or universities had research laboratories in departments of physical education (19). By 1966, 151 institutions had research facilities, 58 of them in exercise physiology (37) (p. 526). This expansion was due to the availability of more scientists trained in the research methodology of exercise physiology, the increased number of students attending college due to the GI Bill and student loans, and the increase in federal dollars to improve the research capabilities of universities (11, 35).

"The scholar's work will be multiplied many fold through the contribution of his students." This quote, taken from Montoye and Washburn (26, 27), expresses a view that has helped attract researchers and scholars to universities. Evidence to support this quote was presented in the form of genealogical charts of contributors to the *Research Quarterly* (27). These charts showed the tremendous influence a few people had through their students in the expansion of research in physical education. Probably the best example of this is Thomas K. Cureton, Jr., of the University of Illinois, a central figure in the training of productive researchers in exercise physiology and fitness (see "A Look Back–Important People in Science").

An example of a major university program that can trace its lineage to the Harvard Fatigue Laboratory is found at Pennsylvania State University. Dr. Ancel Keys, a staff member at the Harvard Fatigue Laboratory, brought Henry Longstreet Taylor back to the Laboratory for Physiological Hygiene at the University of Minnesota, where he received his Ph.D. in 1941 (10). Taylor subsequently advised the research work of Elsworth R. Buskirk, who designed and directed the Laboratory for Human Performance Research (Noll Laboratory) at Pennsylvania State University. Noll Laboratory continues in the tradition of the Harvard Fatigue Laboratory with a comprehensive research program of laboratory and field research into basic exercise, environmental, and industrial research questions (9). However, it is clear that excellent research in exercise and environmental physiology is conducted in laboratories other than those that have a tie to the Harvard Fatigue Laboratory. Laboratories are found in physical education departments, physiology departments in medical schools, clinical medicine programs at hospitals, and in independent facilities such as the Cooper Institute for Aerobics Research. The proliferation and specialization of research involving exercise is discussed in the next section.

It should be no surprise that the major issues studied by researchers in exercise physiology have changed over the years. Table 0.2, from Tipton's look at the 50 years following the closing of the Harvard Fatigue Laboratory, shows the subject matter areas that were studied in considerable detail between 1954 and 1994 (35). A great number of these topics fit into the broad area of systemic physiology or were truly applied physiology issues. Although research continues to take place in most of these areas, Tipton believes that many of the most important questions to be addressed in the future will be answered by those with special training in molecular biology. Baldwin (5) supported Tipton's viewpoint and provided a summary of important questions dealing with exercise and chronic disease whose answers are linked to functional genomics and proteomics, important new tools for the molecular biologist. However, he also noted the need for increased research to address physical activity and chronic diseases at the lifestyle and behavioral levels. This "integrated" approach, crossing disciplines and technologies, should be reflected in the academic programs educating the next generation of exercise science students. We recommend the chapters by Tipton (35) and Buskirk and Tipton (11) for those interested in a detailed look at the development of exercise physiology in the United States.