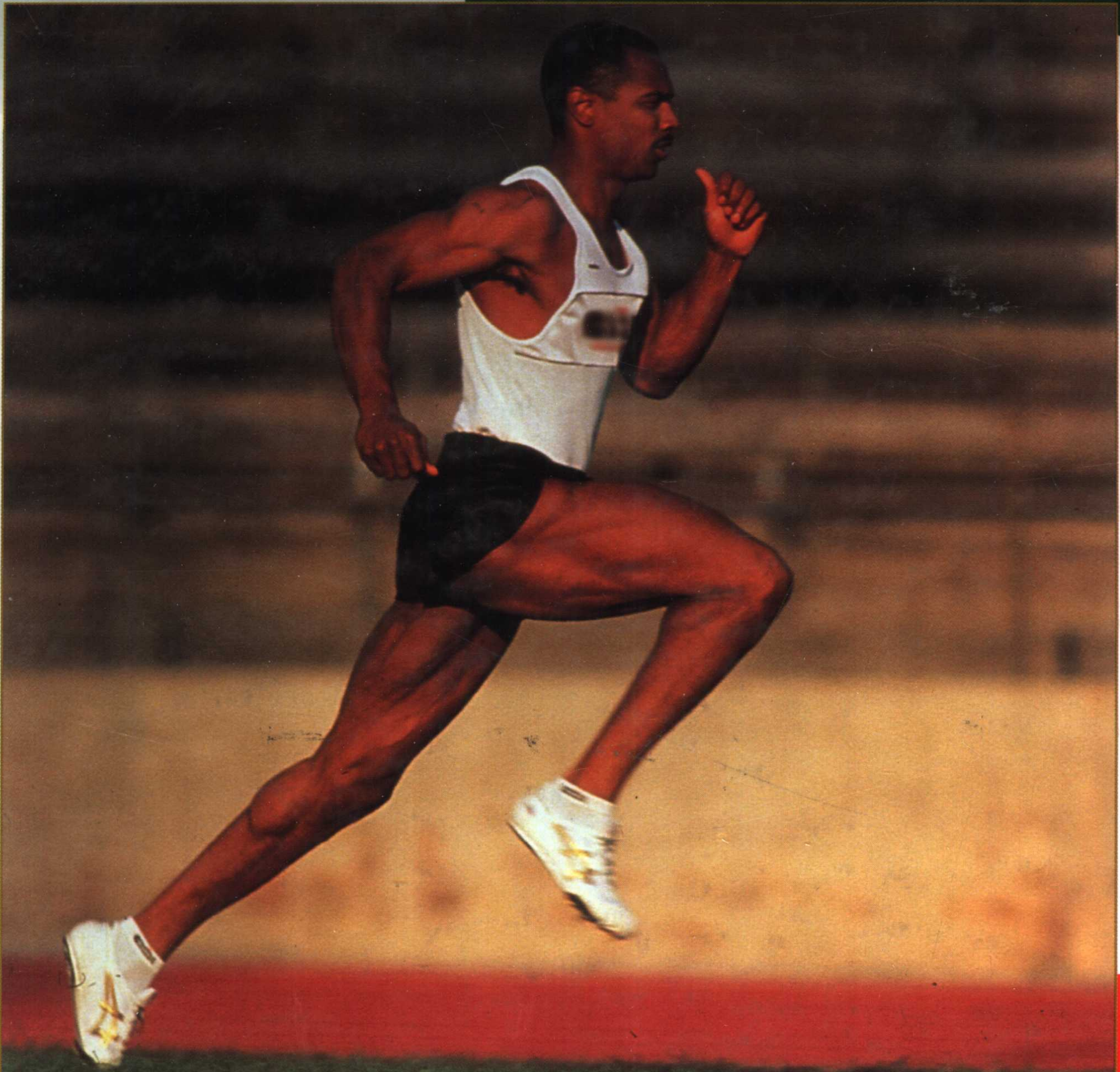
PHYSIOLOGY OF SPORT AND EXERCISE



JACK H. WILMORE \ DAVID L. COSTILL

PHYSIOLOGY OF SPORT AND EXERCISE

Jack H. Wilmore, PhD
Margie Gurley Seay Centennial Professor
Department of Kinesiology and Health Education
University of Texas at Austin

David L. Costill, PhD
John and Janice Fisher Chair in Exercise Science
Director of Human Performance Laboratory
Ball State University
Muncie, Indiana

Human Kinetics

Library of Congress Cataloging-in-Publication Data

Wilmore, Jack H., 1938-
Physiology of sport and exercise / Jack H. Wilmore, David L. Costill.
p. cm.
Includes index.
ISBN 0-87322-693-3
1. Exercise--Physiological aspects. 2. Sports--Physiological aspects. I. Costill, David L. II. Title.
QP301.W6749 1994
612'.044--dc20 94-3913
CIP

ISBN: 0-87322-693-3

Editorial Director: Sue Mauck
Writer: Lori K. Garrett
Developmental Editor: Lori K. Garrett
Assistant Editors: Julie C. Lancaster, Dawn Roselund, Jackie Blakley, Anna Curry, Ed Giles, and John Wentworth
Copyeditor: Thomas Plummer
Proofreader: Pam Johnson
Production Director: Ernie Noa
Text Designer: Keith Blomberg
Photo Editor: Karen Maier
Typesetter: Julie Overholt
Layout Artists: Denise Lowry, Denise Peters, and Tara Welsch
Illustrator: Thomas-Bradley Illustration & Design
Medical Illustrator: Beth Young
Cover Designer: Keith Blomberg
Cover Photographer: John Kelly
Printer: Bang Printing
Binder: Dekker

Printed in the United States of America 10 9 8 7 6 5

Human Kinetics
Web site: http://www.humankinetics.com/

United States: Human Kinetics, P.O. Box 5076, Champaign, IL 61825-5076
1-800-747-4457
e-mail: humank@hkusa.com

Canada: Human Kinetics, Box 24040, Windsor, ON N8Y 4Y9
1-800-465-7301 (in Canada only)
e-mail: humank@hkcanada.com

Europe: Human Kinetics, P.O. Box IW14, Leeds LS16 6TR, United Kingdom
(44) 1132 781708
e-mail: humank@hkeurope.com

Australia: Human Kinetics, 57A Price Avenue, Lower Mitcham, South Australia 5062
(08) 277 1555
e-mail: humank@hkaustralia.com

New Zealand: Human Kinetics, P.O. Box 105-231, Auckland 1
(09) 523 3462
e-mail: humank@hknewz.com

To those who have had the greatest impact on my life: to my lovely wife, Dottie, and our three wonderful daughters, Wendy, Kristi, and Melissa, for their patience, understanding, and love; to Mom and Dad for their love, sacrifice, direction, and encouragement; to my students, who are a continual source of joy and inspiration; and to my Lord, Jesus Christ, who is always there providing for every one of my needs.

Jack H. Wilmore

To my mother and father:
Helen Frances Costill
1914-1993
Bruce Calvin Costill
1911-1972

David L. Costill

Acknowledgments

We would like to thank Rainer Martens for accepting the challenge of trying something new and different and for putting up with a couple of old dogs who were resistant to trying any new tricks. Rainer and the staff at Human Kinetics have been supportive of our many demands and have been extremely dedicated to publishing a quality product. Special recognition must go to Sue Mauck, Editorial Director, who kept this project on a tight timeline, and to Julie Lancaster, for her endless hours of editorial assistance. But most importantly, Lori Garrett, our Developmental Editor, was the glue that held everything together. Lori had to deal with us almost daily and is largely responsible for taking our ideas and putting them into a rational and logical flow. She made us work hard, but no harder than she did, to make this book come alive. Lori, we owe you a great big thanks!

We appreciate the efforts of Jim Pivarnik, Jack Ewing, Art Weltman, and Bill Kraemer, who read the initial manuscripts and gave us important feedback that was incorporated into this final product. Special thanks also go to Vic Convertino, Ed Coyle, Bob Malina, and Matt Vukovich for reading and reacting to chapters, keeping us focused and on target.

Finally, we thank our families, who put up with our many long hours of isolation while we were writing, rewriting, editing, and finally proofing this book. Their patience and support can never be repaid.

Jack H. Wilmore
David L. Costill

Preface

Your body is an amazingly complex machine. All of its various cells and tissues communicate with each other, and their activities are precisely coordinated. When you think of the numerous processes occurring within your body at any given time, it is truly remarkable that all of the body systems function so well together. Even as you sit reading this, your heart pumps blood throughout your body, your intestines digest and absorb nutrients, your kidneys clear waste products, your lungs bring in oxygen, and your muscles hold this book while your brain concentrates on reading. Although you may feel at rest, your body is physiologically quite active. Imagine, then, how much more active all of your body systems become when you engage in active movement. As your physical activity increases, so does your muscles' physiological activity. Active muscles require more nutrients, more oxygen, more metabolic activity, and thus more efficient clearance of waste products. How does your body respond to the high physiological demands of physical activity?

That is the key question when you study the physiology of sport and exercise, and we answer it in this book. *Physiology of Sport and Exercise* introduces you to the fields of sport and exercise physiology. Our goal is to build upon your foundation of knowledge constructed through basic coursework in human anatomy and physiology by applying the principles you've learned to how the body performs and responds to physical activity.

We begin in chapter 1 with a historical overview of sport and exercise physiology as they have emerged from the parent disciplines of anatomy and physiology, and we explain basic principles that will be used throughout the text. In each of Parts A through C, we review selected physiological systems, focusing on their responses to acute bouts of exercise and finally considering how these systems adapt to long-term exposure to exercise—training. In Part A we focus on how the muscular and nervous systems coordinate to produce body movement. In Part B we address how the basic energy systems provide the energy needed for movement and the role of the endocrine system in regulating metabolism. In Part C we look at the cardiovascular and respiratory systems—how they transport nutrients and oxygen to the active muscles and waste products away from them during physical activity.

We change perspective in Part D to examine the impact of the external environment on physical performance. We consider the body's response to heat and cold, then we examine the impact of low atmospheric pressure that is experienced at altitude, and high atmospheric pressure that is experienced during diving. We conclude by considering the effects of a unique environment—one of little gravity—that is experienced during space travel.

In Part E we shift our attention to how athletes can optimize physical performance. We evaluate the effects of different amounts of training. Moving on, we explore the use of ergogenic aids—substances purported to improve athletic ability. We continue by examining athletes' special dietary needs and how nutrition can be used to enhance performance. Finally, we consider the importance of appropriate body weight for performance.

In Part F we examine unique considerations for specific populations of athletes. We look first at the processes of growth and development and how they affect the performance capabilities of young athletes. We evaluate changes that occur in physical performance as we age and explore the ways that physical activity can prolong our youthfulness. Finally, we examine gender issues and special physiological concerns of female athletes.

In Part G, the final part of the book, we turn our attention to the application of sport and exercise physiology for the prevention and treatment of various diseases and the use of exercise for rehabilitation. We focus on cardiovascular disease, obesity, and diabetes, then we close the book with a discussion of prescribing exercise to maintain health and fitness.

Physiology of Sport and Exercise offers a novel approach to the study of sport and exercise physiology. It is designed for the student reader, with the goal of making your learning easy and enjoyable. This text is comprehensive, but we don't want you to be overwhelmed by either its size or its scope. We have included special features to help you progress through the book. For example, each part is color-coded: Every chapter within a given part has a box of the same color appearing at the edge of its pages. A glance at the table of contents reveals which color corresponds to which text part and what chapters are included in that part. Then, by scanning the colored edges of the pages while the book is closed, you can easily locate the part you're seeking and identify the individual chapters within it.

Once you turn to a part, you will find brief text that describes the contents of that part's chapters. Each chapter then begins with a brief overview and a chapter outline with page numbers to help you locate material. Within a chapter, Key Points are placed in blue boxes for quick reference. Key terms are highlighted in the text in blue, are listed at the end of the chapter, and are defined in the glossary at the end of the book. Review boxes scattered throughout each chapter summarize the major points presented.

At the chapter's end, the key terms are listed so you can check your vocabulary comprehension. Study questions allow you to test your knowledge of the chapter's contents. References, numbered throughout the text, also appear here, as do several selected readings, which provide additional information about any topics of special interest within that chapter. Finally, at the end of the book you will find a comprehensive glossary that includes definitions of all key terms, a thorough index, and, inside the back cover, a table of conversions and metric equivalents for easy reference.

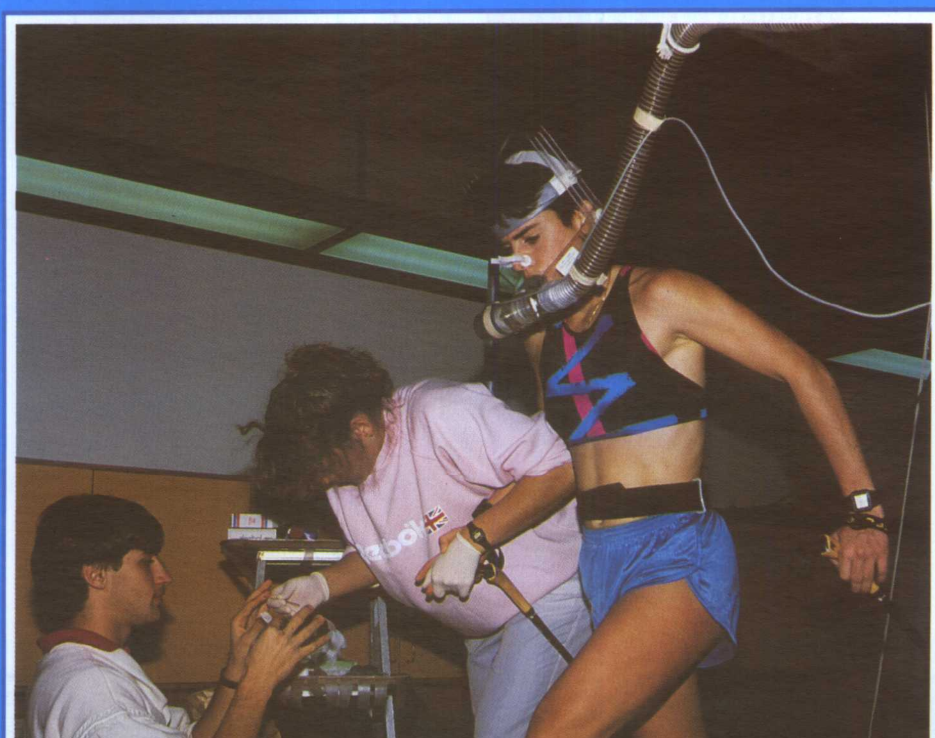
Many of you will read this book only because it is a required text for a required course. But we hope that the information will entice you to continue to study in this relatively new and exciting area. We plan at the very least to further your interest and understanding of your body's marvelous abilities to perform physical work, to adapt to stressful situations, and to improve its physiological capacities. What you learn here is practical not only for anyone who pursues a career in exercise or sport science but also for anyone who wants to be active, healthy, and fit.

Contents

PHYSIOLOGY OF SPORT AND EXERCISE

Chapter 1

An Introduction to Exercise and Sport Physiology



Chapter Overview

The human body is an amazing machine! As you sit reading this chapter, countless perfectly coordinated events are occurring simultaneously in your body. These events allow complex functions, such as hearing, seeing, breathing, and information processing, to continue without your conscious effort. If you stand up, walk out the door, and jog around the block, almost all your body's systems will be called into action, enabling you to successfully shift from rest to exercise. If you continue this routine daily for weeks or months and gradually increase the duration and intensity of your jogging, your body will adapt so you can perform better.

For centuries, scientists have studied how the human body works. During the past several centuries, a small but growing group of scientists have focused their studies on how the body's functioning, or physiology, is altered during physical activity and sport. This chapter will introduce you to exercise and sport physiology, presenting a historical overview then explaining some basic concepts that form a foundation for the chapters that follow.

Chapter Outline

Much of the history of exercise physiology in the United States can be traced to the effort of a Kansas farm boy, David Bruce (D.B.) Dill, whose interest in physiology first led him to study the composition of crocodile blood. Fortunately for us, this young scientist redirected his research to humans when he became the first director of the Harvard Fatigue Laboratory, established in 1927. Throughout his life he was intrigued by the physiology and adaptability of many animals who survive extreme environmental conditions, but he is best remembered for his research on human responses to exercise, heat, high altitude, and other environmental factors. Dr. Dill always served as one of the human "guinea pigs" in these studies. During the Harvard Fatigue Laboratory's 20-year existence, he and his co-workers produced 330 scientific papers along with a classic book entitled *Life, Heat, and Altitude.*[3]

After the Harvard Fatigue Laboratory closed its doors in 1947, he began a second career as deputy director of medical research for the Army Chemical Corps, a position he held until his retirement from that post in 1961. Dr. Dill was then 70 years old—an age he considered too young for retirement—so he moved his exercise research to Indiana University, where he served as a senior physiologist until 1966. In 1967 he obtained funding to establish the Desert Research Laboratory at the University of Nevada at Las Vegas. Dr. Dill used this laboratory as a base for his studies on human tolerance to exercise in the desert and at high altitude. He continued his research and writing until his final retirement at age 93, the same year he produced his last publication, a book entitled *The Hot Life of Man and Beast.*[4] Dr. Dill once bragged to me [DLC] that he was the only scientist to have retired four times.

As the busy executive goes out for her morning jog or the point guard directs his team down the basketball court on a fast break, their bodies must make many adjustments that require a series of complex interactions involving most body systems. Consider a few examples:

- The skeletal system provides the basic framework through which muscles act.
- The cardiovascular system delivers nutrients to the body's various cells and removes waste products.
- The cardiovascular and respiratory systems together provide oxygen to the cells and remove carbon dioxide.
- The integumentary system (skin) helps maintain body temperature by allowing exchange of heat between the body and its surroundings.
- The urinary system helps maintain fluid and electrolyte balance and provides long-term regulation of blood pressure.
- The nervous and endocrine systems coordinate and direct all this activity to meet the body's needs.

Adjustments occur even at the cellular level. For example, to enable muscles to contract, various enzymes are activated and energy is generated.

Physical activity is a complicated process. Scientists must examine each adjustment that the body makes by observing these events both singly and collectively. In this chapter, we will discuss how they approach this task.

The Focus of Exercise and Sport Physiology

Exercise and sport physiology have evolved from anatomy and physiology. Anatomy is the study of an organism's structure, or morphology. From anatomy, we learn the basic structure of various body parts and their interrelationships. Physiology is the study of body function. In physiology, we study how our organ systems, tissues, and cells work and how their functions are integrated to regulate our internal environments. Because physiology focuses on the functions of structures, we can't easily discuss physiology without understanding anatomy.

Exercise physiology is the study of how our bodies' structures and functions are altered when we are exposed to acute and chronic bouts of exercise. Sport physiology further applies the concepts of exercise physiology to training the athlete and enhancing the athlete's sport performance. Thus sport physiology is derived from exercise physiology.

KEY POINT

Exercise physiology has evolved from its parent discipline, physiology. It is concerned with the study of how the body adapts physiologically to the acute stress of exercise, or physical activity, and the chronic stress of physical training. Sport physiology has evolved from exercise physiology. It applies exercise physiology to problems unique to sport.

Let's consider an example to help us distinguish between these two closely related branches of physiology. In exercise physiology, through considerable research, we now better understand how our bodies derive energy from the foods we eat to permit muscle actions to initiate and sustain movement. We have learned that fat is our major energy source when we are at rest and during low-intensity exercise, but that our bodies use proportionately more carbohydrate as exercise intensity increases, until carbohydrate becomes our primary energy source. Prolonged high-intensity exercise can substantially reduce our bodies' carbohydrate stores, which can contribute to exhaustion.

Sport physiology then takes this information and, realizing that the body has limited carbohydrate energy stores, attempts to find ways to

- increase the body's carbohydrate storage capacity (carbohydrate loading),
- decrease the rate at which the body utilizes carbohydrate during physical performance (carbohydrate sparing), and
- improve the athlete's diet both before and during competition to minimize the risk of depleting carbohydrate stores.

The area of sport nutrition, a subdiscipline of sport physiology, is one of the most rapidly growing areas of research in this field.

As another example, exercise physiology has uncovered an important sequence of events that occur when the body is trained beyond its ability to adapt, a condition known as overtraining. Sport physiology has applied this information to both the design and the evaluation of training programs to reduce the risk of overtraining.

But sport physiology is not merely applied exercise physiology. Because exercise physiology also has its own applications, it is often hard to clearly distinguish the two. For this reason, exercise and sport physiology are often considered together, as they are in this text. Now let's look at how exercise physiology, the parent discipline of sport physiology, has evolved through the years.

A Historical Perspective

As a beginning student of exercise physiology, you might be tempted to think that the information in this book is new and is the final word on each topic. Contributions of contemporary exercise physiologists might seem to present new ideas never before treated to the rigors of science, but this is not the case. Rather, the information we'll explore represents the lifelong efforts of many outstanding scientists who have helped piece together the puzzle of human movement. Often, the thoughts and theories of today's physiological detectives were shaped by the efforts of scientists who are long forgotten. What we consider as original or new is most often an assimilation of previous findings or the application of basic science to problems in exercise physiology. To help you appreciate this, let's briefly reflect on the history and people that have shaped the field of exercise physiology.

The Beginnings of Anatomy and Physiology

Although the ancient Greeks made a fair start at studying the function of the human body, not until the 1500s were any truly significant contributions made to understanding both the structure and function of the human body. Anatomy was the forerunner of physiology. A landmark text by Andreas Vesalius, entitled *Fabrica Humani Corporis* [*Structure of the Human Body*], published in 1543, changed the direction of future studies. Though Vesalius's book focused primarily on anatomical descriptions of various organs, the book occasionally attempted to explain their functions as well. British historian Sir Michael Foster said, "This book is the beginning, not only of modern anatomy, but of modern physiology. It ended, for all time, the long reign of fourteen centuries of precedent and began in a true sense the renaissance of medicine."[6]

Most early attempts at explaining physiology were either incorrect or so vague that they could be considered only speculation. Attempts to explain how a muscle generates force, for example, were usually limited to a description of its change in size and shape during action because observations were limited to what could be seen with the eye. From such observations, Hieronymus Fabricius (ca. 1574) suggested that a muscle's contractile power resided in its fibrous tendons, not in its "flesh." Anatomists didn't discover the existence of individual muscle fibers until Dutch scientist Anton van Leeuwenhoek introduced the microscope (around 1660). But how these fibers shortened and created force remained a mystery until the middle of the present century, when the intricate workings of muscle proteins could be studied by electron microscopy.

The Emergence of Exercise Physiology

Exercise physiology is a relative newcomer to the world of science. Before the late 19th century, physiologists' major goal was to gain information of clinical value. The body's response to exercise received almost no attention. Although the value of regular physical activity was well known in the mid-1800s, the physiology of muscular activity gained little attention until the latter part of that century.

The first published textbook on exercise physiology was written by Fernand LaGrange in 1889, entitled *Physiology of Bodily Exercise*.[9] Considering the small amount of research on exercise that had been conducted at that time, it is intriguing to read the author's accounts of such topics as "Muscular Work," "Fatigue," "Habituation to Work," and "The Office of the Brain in Exercise." This early attempt to explain the body's response to exercise was, in many ways, limited to a lot of rambling theory and little fact. Although some basic concepts of exercise biochemistry were emerging at that time, LaGrange was quick to admit that many details were still in the formative stages. For example, he stated that "... vital combustion (energy metabolism) has become very complicated of late; we may say that it is somewhat perplexed, and that it is difficult to give in a few words a clear and concise summary of it. It is a chapter of physiology which is being rewritten, and we cannot at this moment formulate our conclusions."[9]

The first published textbook on exercise physiology was an 1889 work by Fernand LaGrange entitled *Physiology of Bodily Exercise*.

During the late 1800s, many theories were proposed to explain the source of energy for muscle contraction. Muscles were known to generate much heat during exercise, so some theories suggested that this heat was used directly or indirectly to cause muscle fibers to shorten. After the turn of the century, Walter Fletcher and Sir Frederick Gowland Hopkins observed a close relationship between muscle action and lactate formation.[5] This observation led to the realization that energy for muscle action is derived from the breakdown of muscle glycogen to lactic acid (chapter 5), though the details of this reaction remained obscure.

Because the energy demands for muscle action are high, this tissue served as an ideal model to help unravel the mysteries of cellular metabolism. In 1921, Archibald (A.V.) Hill (see Figure 1.1) was awarded the Nobel prize for his findings on energy metabolism. At that time, biochemistry was in its infancy, though rapidly gaining recognition through the research efforts of such Nobel laureates as Albert Szent Gorgyi, Otto Meyerhof, August Krogh, and Hans Krebs, who were all actively studying how living cells generate energy.

Although much of Hill's research was conducted with isolated frog muscle, he also conducted some of the first physiological studies on runners. Such studies were possible through the technical contributions of John (J.S.) Haldane, who developed the methods and equipment needed to measure oxygen use during exercise. These and other investigators provided the basic framework for our understanding of whole-body energy production, which became the focus of considerable research during the middle of this century and is incorporated into computer-based systems used to measure oxygen uptake in exercise physiology laboratories today.

The Harvard Fatigue Laboratory

No laboratory has had more impact on the field of exercise physiology than the Harvard Fatigue Laboratory (HFL), founded in 1927. Creation of this laboratory is credited to the insightful planning of world famous biochemist Lawrence J. Henderson, who rec-

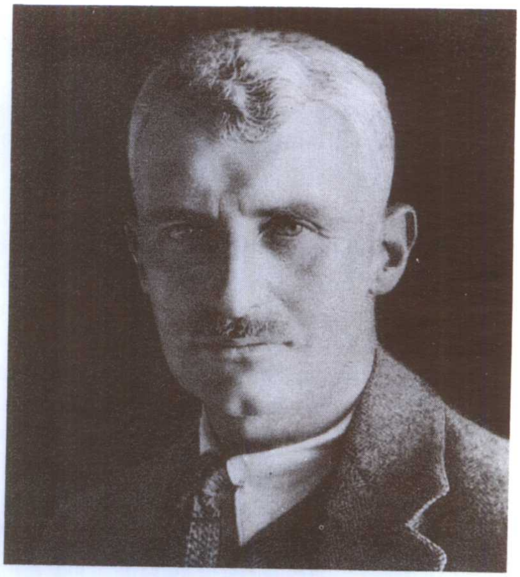


Figure 1.1 1921 Nobel prize winner Archibald (A.V.) Hill (1927).