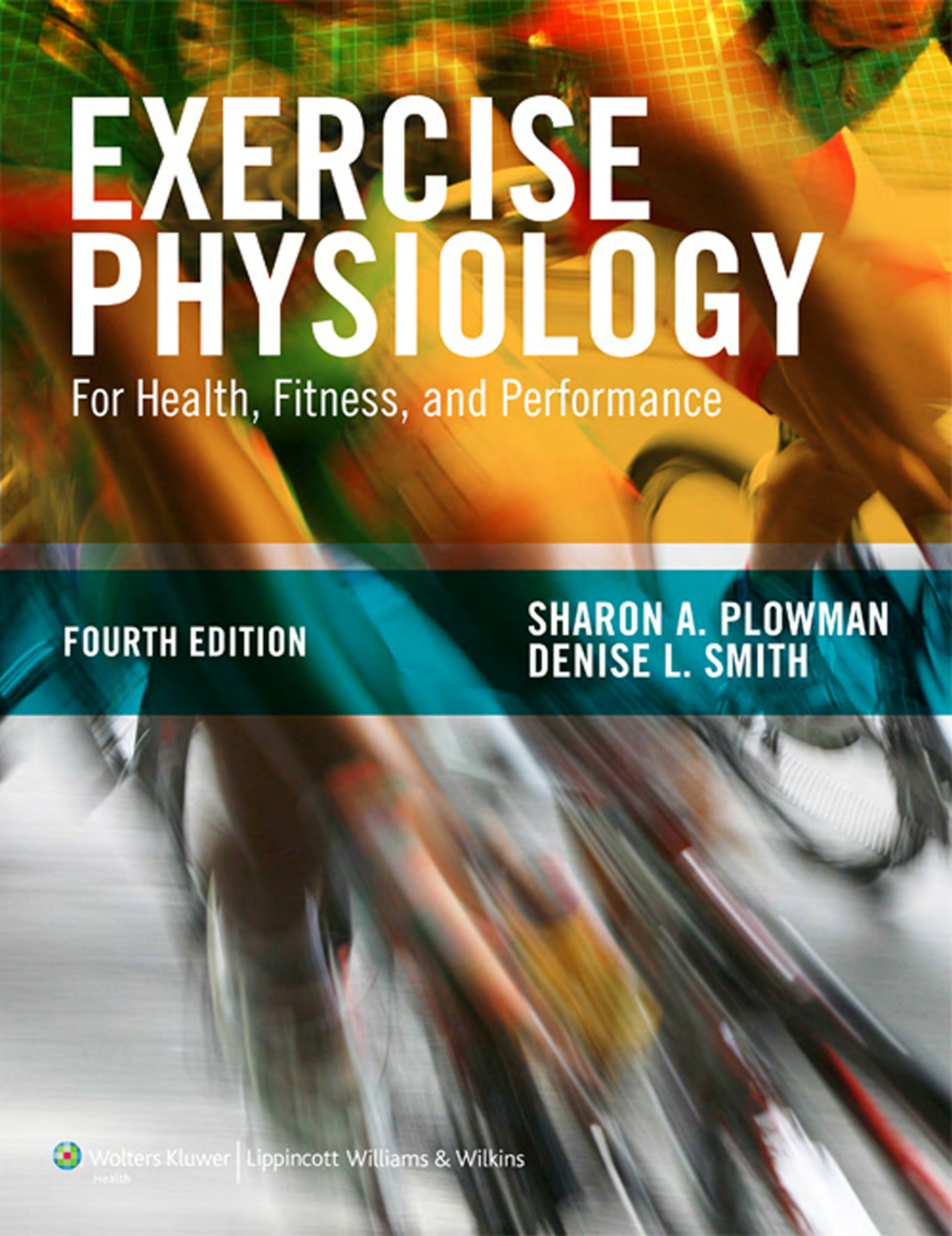

EXERCISE PHYSIOLOGY

For Health, Fitness, and Performance

FOURTH EDITION

SHARON A. PLOWMAN
DENISE L. SMITH

Wolters Kluwer Health | Lippincott Williams & Wilkins

Commonly Used Symbols and Abbreviations

(A-a)PO_2diff	difference between partial pressure of oxygen in alveoli and arterial blood
a-vO_2diff	difference in oxygen content between arterial and venous blood
A	actin
ACh	acetylcholine
ACTH	adrenocorticotrophic hormone
ADH	antidiuretic hormone
ADL	activities of daily living
ADP	adenosine diphosphate
AI	adequate intake
AIDS	acquired immune deficiency syndrome
AMP	adenosine monophosphate
ANS	autonomic nervous system
AP	action potential
ATP	adenosine triphosphate
ATP-PC	phosphagen system
ATPS	atmostpheric temperature and pressure, saturated air
AV	atrioventricular
BCAA	branched chain amino acids
BF	body fat
BMC	bone mineral content
BMD	bone mineral density
BMI	body mass index
BMR	basal metabolic rate
BP	blood pressure
BTPS	body temperature and pressure, saturated air
BW	body weight
CAD	coronary artery disease
CHD	coronary heart disease
CHO	carbohydrate
CNS	central nervous system
CP	creatine phosphate
CR-10	category ratio scale of perceived exertion
D_B	density of the body
D_W	density of water
DBP	diastolic blood pressure
DOMS	delayed-onset muscle soreness
DRI	daily reference intake
DXA	dual-energy X-ray absorptiometry
E	epinephrine
ECG	electrocardiogram
EDV	end diastolic volume
EF	ejection fraction
EIAH	exercise-induced arterial hypoxemia
EMG	electromyogram
EPOC	excess postexercise oxygen consumption
ERT	estrogen replacement therapy
ESV	end systolic volume
ETAP	exercise-related transient abdominal pain
ETS	electron transport system
F_ECO_2	fraction of expired carbon dioxide
F_EN_2	fraction of expired nitrogen
F_EO_2	fraction of expired oxygen
F_G	fraction of a gas
F_ICO_2	fraction of inspired carbon dioxide
F_IN_2	fraction of inspired nitrogen
F_IO_2	fraction of inspired oxygen
f	frequency
FAD	flavin adenine dinucleotide
FEV	forced expiratory volume
FFA	free fatty acids
FFB	fat-free body mass
FFM	fat-free mass
FFW	fat-free weight
FG	fast twitch, glycolytic muscle fibers
FI	fatigue index
FOG	fast twitch, oxidative-glycolytic muscle fibers
FT	fast twitch muscle fibers
GAS	General Adaptation Syndrome
GH	growth hormone
GLUT-1	non-insulin regulated glucose transporter
GLUT-4	insulin regulated glucose transporter
GTO	Golgi tendon organ
Hb	hemoglobin
HbO_2	oxyhemoglobin
HDL-C	high-density lipoprotein
HIV	human immunosupression virus
HR	heart rate
HRmax	maximal heart rate
HRR	heart rate reserve
HT	height
ICD	isocitrate dehydrogenase
ICP	isovolumetric contraction period
IRP	isovolumetric relaxation period
LA	lactic acid/glycolytic system
LBM	lean body mass
LBP	low back pain
LDL-C	low-density lipoprotein
LSD	long, slow distance
LT	lactate threshold
M_A	mass of the body in the air
M_W	mass of the body underwater
M	myosin
MAOD	maximal accumulated oxygen deficit
MAP	mean arterial pressure
MCT1	extracellular and intracellular monocarboxylate lactate transporter
MCT4	extracellular monocarboxylate lactate transporter
MET	metabolic equivalent
MLSS	maximal lactate steady state

MP	mean power
MVC	maximal voluntary contraction
MVV	maximal voluntary ventilation
NAD	nicotinamide adenine dinucleotide
NE	norepinephrine
NK	natural killer
NKCA	natural killer cell activity
NMJ	neuromuscular junction
NMS	neuromuscular spindle
NT	neurotransmitter
OBLA	onset of blood lactate accumulation
OP	oxidative phosphorylation
OTS	overtraining syndrome
P_A	pressure in the alveoli
P_ACO_2	partial pressure of carbon dioxide in the alveoli
P_AO_2	partial pressure of oxygen in the alveoli
P_B	barometric pressure
P_G	partial pressure of a gas
P_i	inorganic phosphate
P	pressure
$PaCO_2$	partial pressure of carbon dioxide in arterial blood
PaO_2	partial pressure of oxygen in arterial blood
PC	phosphocreatine
PCO_2	partial pressure of carbon dioxide
PFK	phosphofructokinase
pH	hydrogen ion concentration
PN_2	partial pressure of nitrogen
PNF	proprioceptive neuromuscular facilitation
PNS	peripheral nervous system
PO_2	partial pressure of oxygen
PP	peak power
PRO	protein
PvO_2	partial pressure of oxygen in venous blood
$PvCO_2$	partial pressure of carbon dioxide in venous blood
$\dot{Q}$	cardiac output
R_a	rate of appearance
R_d	rate of disappearance
R	resistance
RBC	red blood cells
RDA	recommended daily allowance
RER	respiratory exchange ratio
RH	relative humidity
RHR	resting heart rate
RM	repetition maximum
RMR	resting metabolic rate
RMT	respiratory muscle training
ROM	range of motion
RPE	rating of perceived exertion
RPP	rate pressure product
RQ	respiratory quotient
RV	residual volume
$SaO_2\%$	percent saturation of arterial blood with oxygen
$SbO_2\%$	percent saturation of blood with oxygen
$SvO_2\%$	percent saturation of venous blood with oxygen
SBP	systolic blood pressure
SO	slow twitch, oxidative muscle fibers
SR	sarcoplasmic reticulum
SSC	stretch shortening cycle
ST	slow-twitch muscle fibers
STPD	standard temperature and pressure, dry air
SV	stroke volume
T	temperature
T_{amb}	ambient temperature
TC	total cholesterol
T_{co}	core temperature
TEF	thermic effect of feeding
TEM	thermic effect of a meal
TExHR	target exercise heart rate
$TEx\dot{V}O_2$	target exercise oxygen consumption
TG	triglycerides
TLC	total lung capacity
TPR	total peripheral resistance
T_{re}	rectal temperature
T_{sk}	skin temperature
T_{tym}	tympanic temperature
URTI	upper respiratory tract infection
$\dot{V}_A$	alveolar ventilation
V_D	volume of dead space
$\dot{V}_E$	volume of expired air
V_G	volume of a gas
$\dot{V}_I$	volume of inspired air
V_T	tidal volume
$\dot{V}$	volume per unit of time
V	volume
VAT	visceral abdominal tissue
VC	vital capacity
$\dot{V}CO_2$	volume of carbon dioxide produced
VEP	ventricular ejection period
VFP	ventricular filling period
VLDL	very low density lipoproteinn
$\dot{V}O_2$	volume of oxygen consumed
$\dot{V}O_2max$	maximal volume of oxygen consumed
$\dot{V}O_2peak$	peak volume of oxygen consumed
$\dot{V}O_2R$	oxygen consumption reserve
VT	ventilatory threshold
$v\dot{V}O_2max$	velocity at maximal oxygen consumption
W/H	waist-to-hip ratio
WBC	white blood cells
WT	weight

Icon Identification Guide

Short-term, light to moderate submaximal aerobic 

Long-term, moderate to heavy submaximal aerobic 

Incremental aerobic to maximum 

Static 

Dynamic resistance 

Very short-term, high-intensity anaerobic exercise 

Exercise Physiology

FOR HEALTH, FITNESS, AND PERFORMANCE

Fourth Edition

Sharon A. Plowman
Northern Illinois University

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Skidmore College

Wolters Kluwer Health | Lippincott Williams & Wilkins
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Dedication

To our teachers and students,
past, present, and future:
sometimes one and the same.

About the Authors

SHARON A. PLOWMAN earned her Ph.D. at the University of Illinois at Urbana–Champaign under the tutelage of Dr. T. K. Cureton Jr. She is a professor emeritus from the Department of Kinesiology and Physical Education at Northern Illinois University. Dr. Plowman taught for, 36 years, including classes in exercise physiology, stress testing, and exercise bioenergetics. She has published over 70 scientific and research articles in the field as well as numerous applied articles on physical fitness with emphasis on females and children in such journals as *ACSM's Health & Fitness Journal; Annals of Nutrition and Metabolism; Human Biology; Medicine & Science in Sports & Exercise; Pediatric Exercise Science;* and *Research Quarterly for Exercise and Sport*. She is a coauthor of the Dictionary of the Sport and Exercise Sciences (M. H. Anshel ed., 1991) and has published several chapters in other books.

Dr. Plowman is a Fellow Emeritus of the American College of Sports Medicine, and served on the Board of Trustees of that organization from 1980 to 1983. In 1992 she was elected an Active Fellow by the American Academy of Kinesiology and Physical Education. She serves on the Advisory Council for FITNESSGRAM®. The American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD) recognized her with the Mabel Lee Award in 1976 and the Physical Fitness Council Award in 1994. Dr. Plowman received the Excellence in Teaching Award (at Northern Illinois University at the department level in 1974 and 1975 and at the university level in 1975) and the Distinguished Alumni Award from the Department of Kinesiology at the University of Illinois at Urbana–Champaign in 1996. In 2006 the President's Council on Physical Fitness and Sports presented her with their Honor Award in recognition of her contributions made to the advancement and promotion of the science of physical activity.

DENISE L. SMITH is a Professor of Exercise Science and recipient of the Class of 1961 Chair at Skidmore College. She also serves as the Director of the First Responder Health and Safety Research Laboratory. With a Ph.D. in kinesiology and specialization in exercise physiology from the University of Illinois at Urbana–Champaign, Dr. Smith has taught for over 20 years, including classes in anatomy and physiology, exercise physiology, clinical aspects of cardiovascular health, cardiorespiratory aspects of human performance, neuromuscular aspects of human performance, and research design. Her research is focused on the cardiovascular strain associated with heat stress, particularly as it relates to cardiac, vascular, and coagulatory function. She has published her research findings in such journals as *American Journal of Cardiology; Cardiology in Review; Medicine & Science in Sports & Exercise; Vascular Medicine; Ergonomics; European Journal of Applied Physiology; Journal of Applied Physiology;* and *Journal of Cardiopulmonary Rehabilitation*. She is also a coauthor of "Advanced Cardiovascular Exercise Physiology," an upper-level text that is part of the Advanced Exercise Physiology series.

Dr. Smith is a Fellow in the American College of Sports Medicine and has served as secretary for the Occupational Physiology Interest Group and as a member of the National Strategic Health Initiative Committee. She has served on the executive board and as an officer for the Mid-Atlantic Regional Chapter of ACSM. She is a member of the National Fire Protection Agency Technical Committee on Fire Service Occupational Safety and Health. She is also a Research Scientist at the University of Illinois Fire Service Institute at Urbana–Champaign.

Preface

The fourth edition of *Exercise Physiology for Health, Fitness, and Performance* builds upon and expands the strength of the first three editions. The purpose of the current edition, however, remains unchanged from that of the first three editions. That is, the goal is to present exercise physiology concepts in a clear and comprehensive way that will allow students to apply fundamental principles of exercise physiology in the widest variety of possible work situations. The primary audience is kinesiology, exercise science, health, coaching, and physical education majors and minors, including students in teaching preparation programs and students in exercise and sport science tracts where the goal is to prepare for careers in fitness, rehabilitation, athletic training, or allied health professions.

As with other textbooks in the field, a great deal of information is presented. Most of the information has been summarized and conceptualized based on extensive research findings. However, we have occasionally included specific research studies to illustrate certain points, believing that students need to develop an appreciation for research and the constancy of change that research precipitates. **Focus on Research** boxes, including some that are labeled as **Clinically Relevant**, are integrated into the text to help students understand how research informs our understanding of exercise physiology and how research findings can be applied in the field. Our definition of the designation "Clinically Relevant" is used in the broadest sense to refer to a variety of situations that students of exercise physiology might find themselves in during an internship situation or eventual employment. All Focus on Research boxes highlight important classic or recent basic and applied studies in exercise physiology, as well as relevant experimental design considerations.

All chapters are thoroughly referenced and a complete list of references is provided at the end of each chapter. These references should prove to be a useful resource for students to explore topics in more detail for laboratory reports or term projects. The extensive referencing also reinforces the point that our knowledge in exercise physiology is based on a foundation of rigorous research.

The body of knowledge in exercise physiology is extensive and growing every day. Each individual faculty member must determine what is essential for his or her students. To this end, we have tried to allow for choice and flexibility, particularly in the organization of the content of the book.

A Unique Integrative Approach

The intent of this textbook is to present the body of knowledge based on the traditions of exercise physiology but in a way that is not bound by those traditions. Instead of proceeding from a unit on basic science, through units of applied science, to a final unit of special populations or situations (which can lead to the false sense that scientific theories and applications can and should be separated), we have chosen a completely integrative approach to make the link between basic theories and applied concepts both strong and logical.

Flexible Organization

The text begins with an introductory chapter: The Warm-Up. This chapter is intended to prepare students for the chapters that follow. It explains the text's organization, provides an overview of exercise physiology, and establishes the basic terminology and concepts that will be covered in each unit. Paying close attention to this chapter will help the student when studying the ensuing chapters.

Four major units follow: Metabolic System, Cardiovascular-Respiratory System, Neuromuscular-Skeletal System, and Neuroendocrine Immune System. Although the units are presented in this order, each unit can stand alone and has been written in such a way that it may be taught before or after each of the other three with the assumption that Chapter 1 (The Warm-Up) will always precede whichever unit the faculty member decides to present first. Figure 1.1 depicts the circular integration of the units reinforcing the basic concepts that all of the systems of the body respond to exercise in an integrated way and that the order of presentation can logically begin with any unit. Unit openers and graphics throughout the text reinforce this concept.

Consistent Sequence of Presentation

To lay a solid pedagogical foundation, the chapters in each unit follow a consistent sequence of presentation: basic anatomy and physiology, the measurement and meaning of variables important to understanding exercise physiology, exercise responses, training principles and adaptations, and special applications, problems, and considerations.

Basic Sciences

It is assumed that the students using this text will have had a basic course in anatomy, physiology, chemistry, and math. However, sufficient information is presented in the basic chapters to provide a background for what follows if this is not the case. For those students with a broad background, the basic chapters can serve as a review; for those students who do not need this review, the basic chapters can be de-emphasized.

Measurement

Inclusion of the measurement sections serves two purposes—to identify how the variables most frequently used in exercise physiology are obtained and to contrast criterion or laboratory test results with field test results. Criterion or laboratory results are essential for accurate determination and understanding of the exercise responses and training adaptations, but field test results are often the only items available to professionals in school or health club settings.

Exercise Responses and Training Adaptations

The chapters or sections on exercise responses and training adaptations present the definitive and core information for exercise physiology. Exercise response chapters are organized by exercise modality and intensity. Specifically, physiological responses to the following six categories of exercise (based on the duration, intensity, and type of muscle contraction) are presented when sufficient data are available: (1) short-term, light to moderate submaximal aerobic exercise; (2) long term, moderate to heavy submaximal aerobic exercise; (3) incremental aerobic exercise to maximum; (4) static exercise; (5) dynamic resistance exercise; and (6) very short-term, high intensity anaerobic exercise. Training principles for the prescription of exercise training programs are presented for each physical fitness component: aerobic and anaerobic metabolism, body composition, cardiovascular endurance, muscular strength and endurance, and flexibility and balance. These principles are followed by the training adaptations that will result from a well-prescribed training program.

Special Applications

The special applications chapters always relate the unit topic to health-related fitness and then deal with such diverse topics as altitude and thermoregulation (Cardiovascular-Respiratory Unit); making weight and eating disorders (Metabolic Unit); muscle fatigue and soreness (Neuromuscular-Skeletal Unit); and Overreaching/Overtraining Syndrome (Neuroendocrine Immune Unit). **Focus on Application** and **Focus on Application—Clinically Relevant** boxes emphasize how research and underlying exercise physiology principles are relevant to the practitioner.

Complete Integration of Age Groups and Sexes

A major departure from tradition in the organization of this text is the complete integration of information relevant to all age groups and both sexes. In the past, there was good reason to describe evidence and derive concepts based on information from male college students and elite male athletes. These were the samples of the population most involved in physical activity and sport, and they were the groups most frequently studied. As more women, children, and older adults began participating in sport and fitness programs, information became available on these groups. Chapters on females, children/adolescents, and the elderly were often added to the back of an exercise physiology text as supplemental material. However, most physical education, kinesiology, and exercise science professionals will be dealing with both male and female children and adolescents in school settings, average middle-aged adults in health clubs or fitness centers, and older adults in special programs. Very few will be dealing strictly with college-aged students, and fewer still will work with elite athletes. This does not mean that information based on young adult males has been excluded or even de-emphasized. However, it does mean that it is time to move coverage of the groups that make up most of the population from the back of the book and integrate information about males and females at various ages throughout the text. That being said, these sections are typically stand-alone, allowing the faculty member to give the individual students freedom to select a population they are primarily interested in.

Pedagogical Considerations

This text incorporates multiple pedagogical techniques to support student learning. These techniques include a list of learning objectives at the beginning of each chapter as well as a chapter summary, review questions, and references at the end of each chapter. Another pedagogical aid is the use of a running glossary. Terms are highlighted in definition boxes as they are introduced and are highlighted and defined in the text where they first appear to emphasize the context in which they are used. A glossary is included in the back matter of the book for easy reference. Additional important technical terms with which students should be familiar are italicized in the text to emphasize their importance. Because so many are used, a complete list of commonly used symbols and abbreviations with their meanings is printed on the front endpapers of the text for quick and easy reference. Each chapter contains a multitude of tables, charts, diagrams, and photographs to underscore the pedagogy, to aid in the Organization of material, and to enhance the visual appeal of the text.

Unique Color-Coding

A unique aspect of the graphs is color-coding, which allows for quick recognition of the condition represented. Because it is so critical to recognize the differences among exercise responses to different types of exercise, we use a specific background color for each category of exercise. Further, we differentiate the responses to an acute bout of exercise from training adaptations that occur as a result of a consistent training program with a specific background color. For exercise response patterns, each of the six exercise categories has its own shaded representative color and accompanying icon. A key to these colors and icons is included in Table 1.2.

Active Learning

Throughout the text, **Check Your Comprehension** boxes engage the student in active learning beyond just reading. In some instances, the boxes require students to work through problems that address their understanding of the material. In other instances, students are asked to interpret a set of circumstances or deduce an answer based on previously presented information. Scattered throughout the text and occasionally used in Check Your Comprehension boxes are equations and problems used to calculate specific variables in exercise physiology. Examples using all equations are included in discrete sections in the text. Individual faculty members can determine how best to use or not use these portions of the text to best fit their individual situations and student needs. Each chapter ends with a set of essay review questions.

Appendices

Appendix A provides information on the metric system, units, symbols, and conversion both with and between the metric and English systems. Appendix B offers supplementary material, consisting of three parts that deal with aspects of oxygen consumption calculation. Appendix C provides Answers to the Check Your Comprehension boxes that appear throughout the text.

Online Resources

A comprehensive set of ancillary materials designed to facilitate classroom preparation and ease the transition into a new text is available to students and instructors using *Exercise Physiology for Health*, *Fitness*, *and Performance*, *Fourth Edition*.

For Students

- E-book
- Crossword puzzles using key terms and definitions. Answers are accessible.
- Quiz Bank, including multiple choice and drop and drag questions to assist in studying the material or for self-testing. Answers are accessible.
- Worksheets that include true/false questions (with space for correcting false statements), fill-in tables, figure labeling, matching, and calculation to assist in studying or for self-testing. Worksheet answers are also available to students.
- Laboratory manual
- Online animations

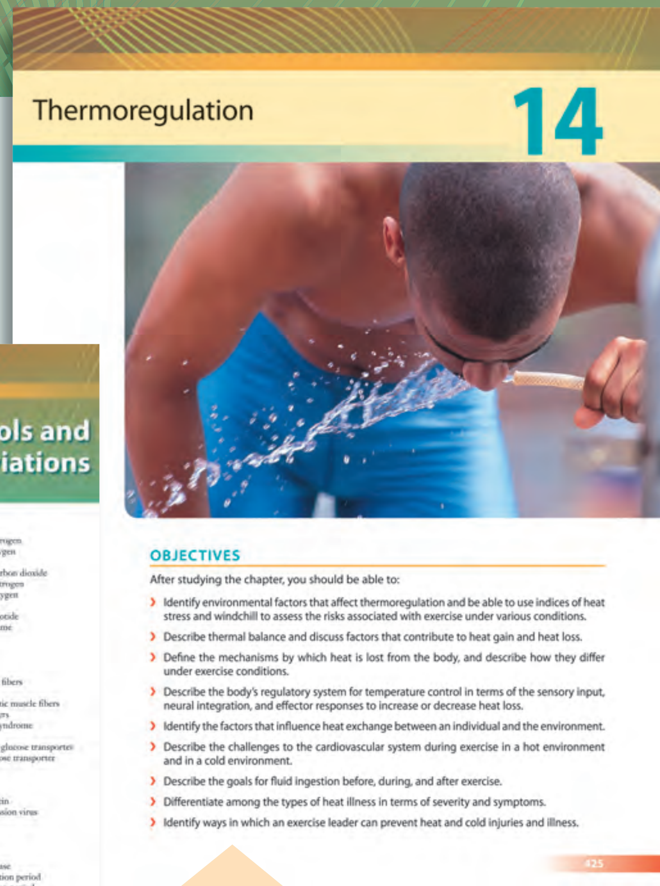
For Faculty

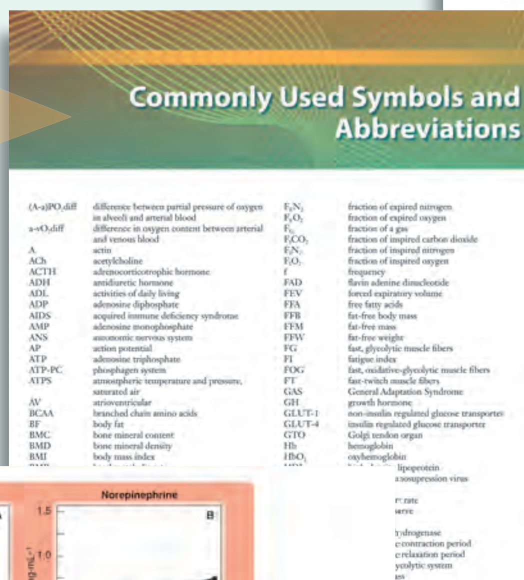
- E-book
- Image bank of all figures in the text
- PowerPoint lecture outlines
- Brownstone test generator
- Answers to in-text chapter review questions

User's Guide

This User's Guide explains the key features found in the fourth edition of *Exercise Physiology for Health, Fitness, and Performance.*

Get the most out of your learning and study time so you can master exercise physiology principles and move on to career success!



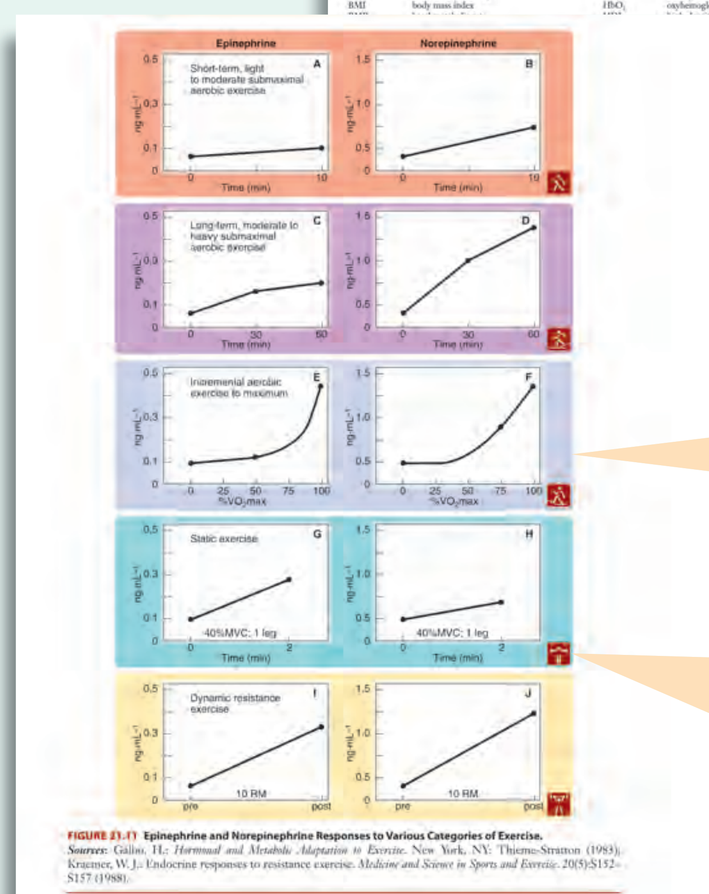


Commonly Used Symbols and Abbreviations

You can find this useful resource just inside the front cover of the text.

Chapter Objectives

These are the learning objectives that you need to meet after reading the chapter.

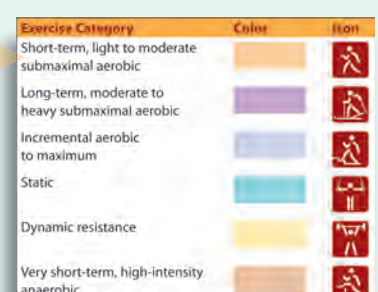


Data Graphs

Each chapter contains a multitude of graphs, tables, charts, and diagrams that clarify and enhance points made in the text.

Icons and Color Coding

Color tints and bold icons within figures and figure legends help you quickly distinguish the exercise response to six different categories of exercise.



Focus on Research Boxes

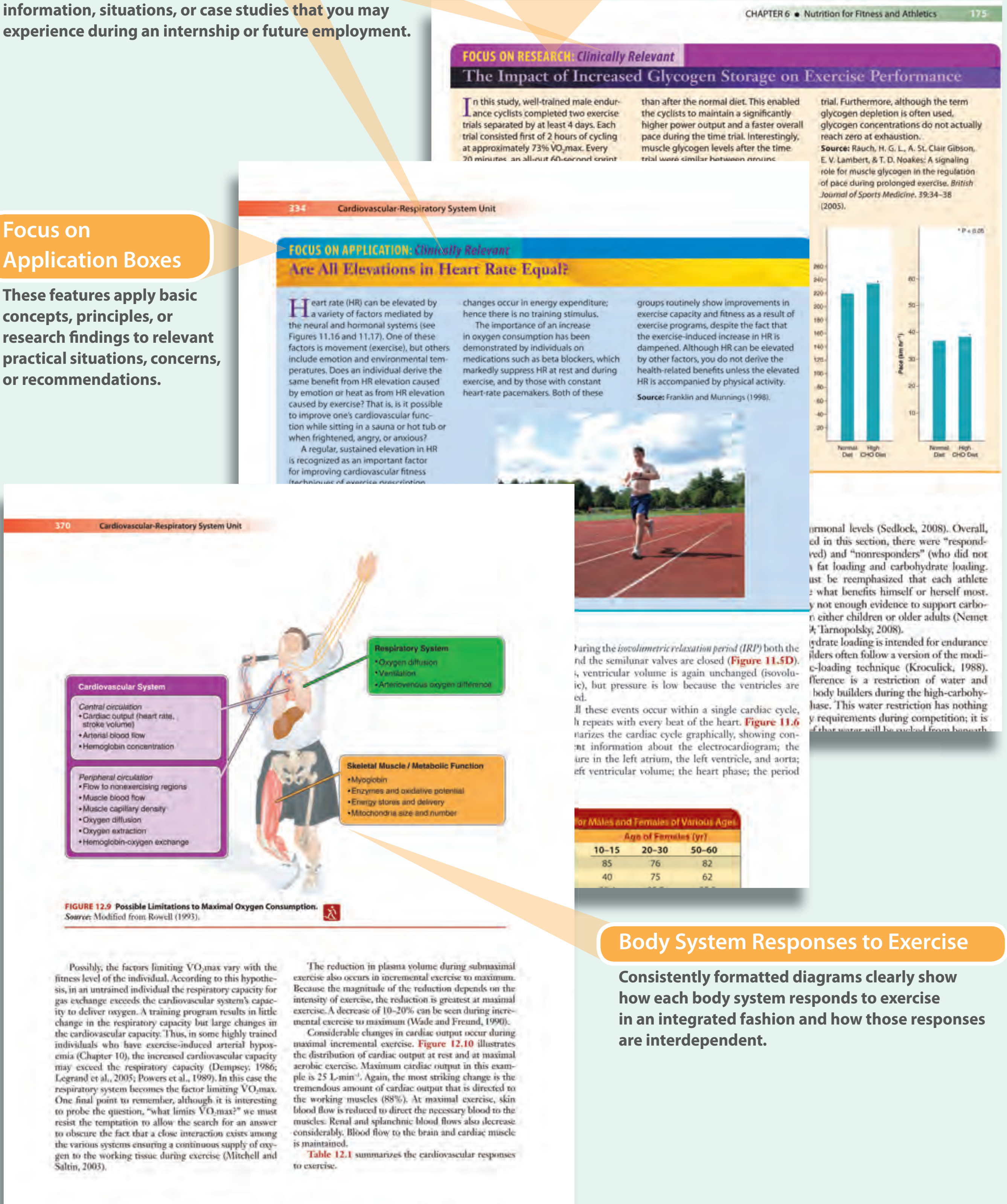
Classic, illustrative, and cutting-edge research studies are presented to help you develop an appreciation for how research affects changing practices in the field.

Clinically Relevant Boxes

Specially identified boxes highlight clinical information, situations, or case studies that you may experience during an internship or future employment.

Focus on Application Boxes

These features apply basic concepts, principles, or research findings to relevant practical situations, concerns, or recommendations.

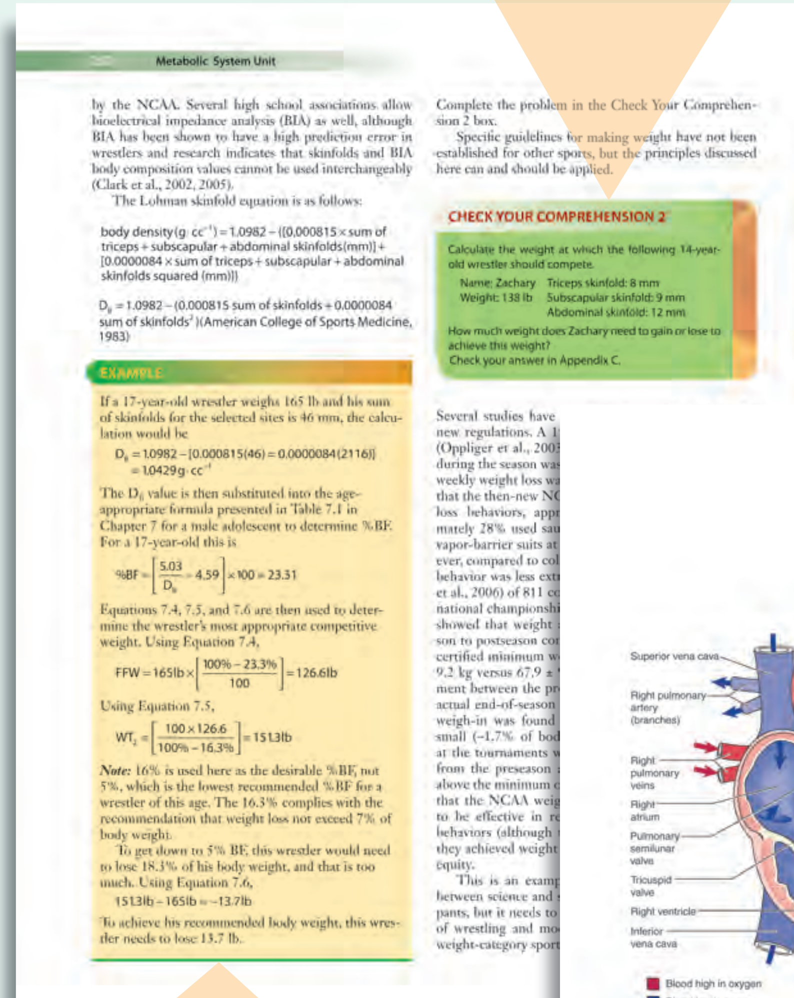


Body System Responses to Exercise

Consistently formatted diagrams clearly show how each body system responds to exercise in an integrated fashion and how those responses are interdependent.

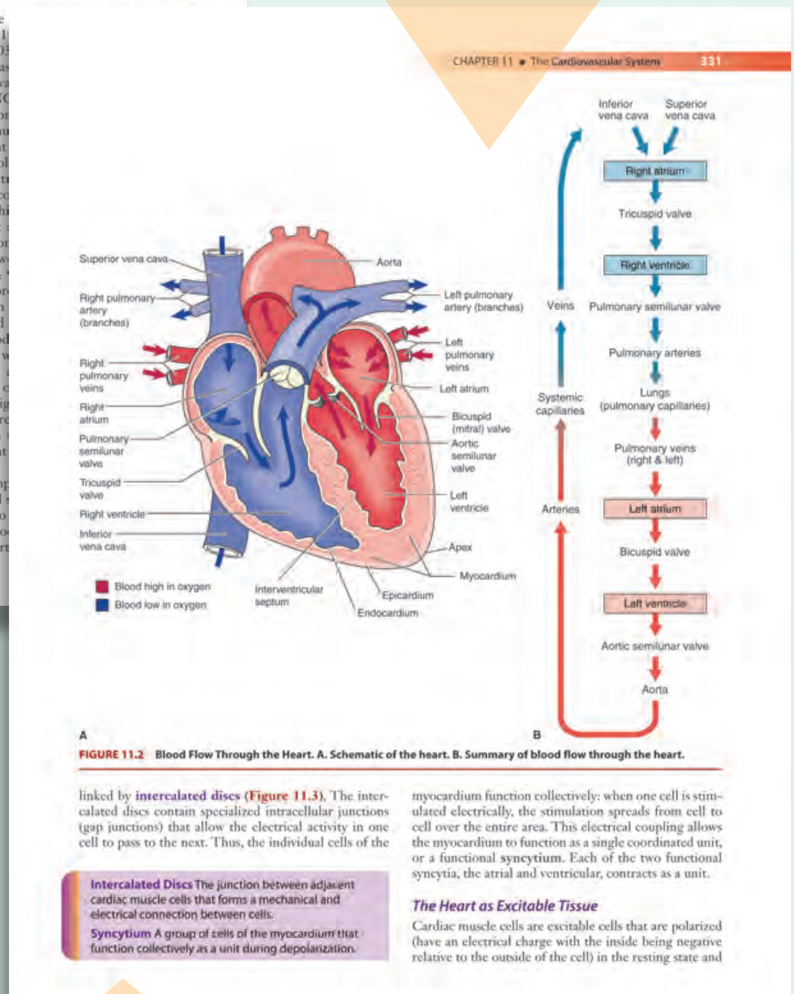
Check Your Comprehension Boxes

These engaging mini-quizzes challenge you to work through problems, interpret circumstances, or deduce answers to reinforce your learning as you move through each chapter.



Clear and Accurate Artwork

Detailed anatomic illustrations and practice-related photos place key concepts in context.



Example Boxes

These highlighted equations enable you to visualize working out problems and calculate specific variables in exercise physiology.

Definition Boxes

Important terms are boldfaced in the text where they first appear to emphasize the context in which they are used. Definitions are provided in a callout box to create an on-the-spot glossary.

Chapter Review Questions

Essay-style questions help you build your critical-thinking, problem-solving, and decision-making skills.

Chapter Summaries

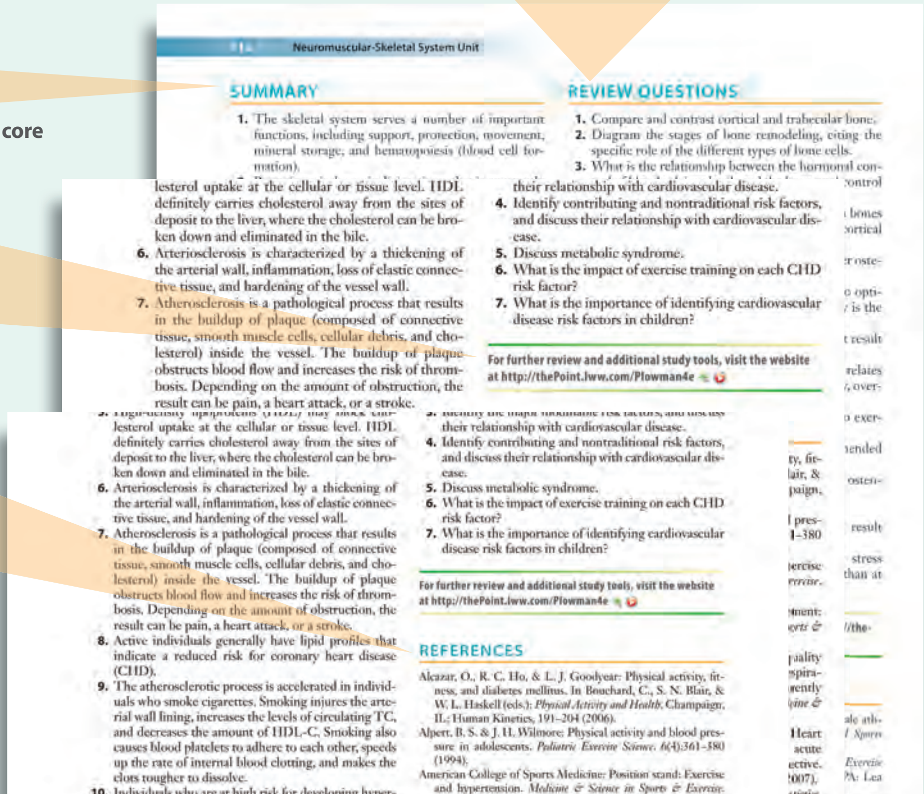
Concise copy points review the chapter's core content.

Online Animations and Other Resources

Icons throughout the text direct readers to useful resources that are available online.

References and Suggested Readings

Key published articles are identified for further in-depth exploration and can be used as a source of additional information for laboratory reports and class papers.



Neuromuscular-Skeletal System Unit

SUMMARY

1. The skeletal system serves a number of important functions, including support, protection, movement, mineral storage, and hematopoiesis (blood cell formation).

REVIEW QUESTIONS

1. Compare and contrast cortical and trabecular bone.
2. Diagram the stages of bone remodeling, citing the specific role of the different types of bone cells.
3. What is the relationship between the hormonal control ...

lesterol uptake at the cellular or tissue level. HDL definitely carries cholesterol away from the sites of deposit to the liver, where the cholesterol can be broken down and eliminated in the bile.

6. Arteriosclerosis is characterized by a thickening of the arterial wall, inflammation, loss of elastic connective tissue, and hardening of the vessel wall.
7. Atherosclerosis is a pathological process that results in the buildup of plaque (composed of connective tissue, smooth muscle cells, cellular debris, and cholesterol) inside the vessel. The buildup of plaque obstructs blood flow and increases the risk of thrombosis. Depending on the amount of obstruction, the result can be pain, a heart attack, or a stroke.
8. Active individuals generally have lipid profiles that indicate a reduced risk for coronary heart disease (CHD).
9. The atherosclerotic process is accelerated in individuals who smoke cigarettes. Smoking injures the arterial wall lining, increases the levels of circulating TC, and decreases the amount of HDL-C. Smoking also causes blood platelets to adhere to each other, speeds up the rate of internal blood clotting, and makes the clots tougher to dissolve.

their relationship with cardiovascular disease.

4. Identify contributing and nontraditional risk factors, and discuss their relationship with cardiovascular disease.
5. Discuss metabolic syndrome.
6. What is the impact of exercise training on each CHD risk factor?
7. What is the importance of identifying cardiovascular disease risk factors in children?

For further review and additional study tools, visit the website at http://thePoint.lww.com/Plowman4e

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ADDITIONAL LEARNING AND TEACHING RESOURCES

Learning goes beyond the pages of this textbook! Interactive materials are available to students and faculty via thePoint companion Website.

thePoint

http://thePoint.lww.com/Plowman4e

Dynamic 3-D animation clips bring key concepts to life.

Log on to thePoint with your personal access code to access all of these valuable tools:

Student Resource Center

- Full Text Online
- Crossword Puzzles: Key Terms and Definitions
- Quiz Bank Questions
  - Multiple Choice
  - Drop & Drag
- Worksheets
  - True/false (with space for corrections)
  - Tables to fill in
  - Matching
  - Calculations
- Laboratory Manual
- Reference List of American College of Sports Medicine Position Stands
- Answers to Crossword Puzzles, Quiz Bank Questions and all Worksheets

Faculty Resource Center

- E-book
- Image bank of all figures in text
- PowerPoint lecture outlines
- Brownstone test generator
- Answers to in-text chapter review questions.

Acknowledgments

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Sharon A. Plowman
Denise L. Smith

Contents

The Warm-Up

1

OBJECTIVES

After studying the chapter, you should be able to:

- Describe what exercise physiology is and discuss why you need to study it.
- Identify the organizational structure of this text.
- Differentiate between exercise responses and training adaptations.
- List and explain the six categories of exercise whose responses are discussed throughout this book.
- List and explain the factors involved in interpreting an exercise response.
- Describe the graphic patterns that physiological variables may exhibit in response to different categories of exercise and as a result of training adaptations.
- List and explain the training principles.
- Describe the differences and similarities between health-related and sport-specific physical fitness.
- Define and explain periodization.
- Define detraining.
- Relate exercise and exercise training to Selye's theory of stress.

Introduction

In the 1966 science fiction movie *Fantastic Voyage* (CBS/Fox), a military medical team is miniaturized in a nuclear-powered submarine and injected through a hypodermic needle into the carotid artery. Anticipating an easy float into the brain, where they plan to remove a blood clot by laser beam, they are both awed by what they see and imperiled by what befalls them. They see erythrocytes turning from an iridescent blue to vivid red as oxygen bubbles replace carbon dioxide; nerve impulses appear as bright flashes of light; and when their sub loses air pressure, all they need to do is tap into an alveolus. Not all of their encounters are so benign, however. They are sucked into a whirlpool caused by an abnormal fistula between the carotid artery and jugular vein. They have to get the outside team to stop the heart so that they will not be crushed by its contraction. They are jostled about by the conduction of sound waves in the inner ear. They are attacked by antibodies. And finally, their submarine is destroyed by a white blood cell—they are, after all, foreign bodies to the natural defense system. Of course, in the end, the "good guys" on the team escape through a tear duct, and all is well.

Although the journey you are about to take through the human body will not be quite so literal, it will be just as incredible and fascinating, for it goes beyond the basics of anatomy and physiology into the realm of the moving human. The body is capable of great feats, whose limits and full benefits in terms of exercise and sport are still unknown.

Consider these events and changes, all of which have probably taken place within the life span of your grandparents.

- President Dwight D. Eisenhower suffered a heart attack on September 23, 1955. At that time, the normal medical treatment was 6 weeks of bed rest and a lifetime of curtailed activity (Hellerstein, 1979). Eisenhower's rehabilitation, including a return to golf, was, if not revolutionary, certainly progressive. Today, cardiac patients are mobilized within days and frequently train for and safely run marathons.
- The 4-minute mile was considered an unbreakable limit until May 6, 1954, when Roger Bannister ran the mile in 3:59.4. Hundreds of runners (including some high school boys) have since accomplished that feat. The men's world record for the mile, which was set in 1999, is 3:43.13. The women's mile record, of 4:12.56 set in 1996, is approaching the old 4-minute "barrier."

Exercise Physiology A basic and an applied science that describes, explains, and uses the body's response to exercise and adaptation to exercise training to maximize human physical potential.

- The 800-m run was banned from the Olympics from 1928 to 1964 for women because females were considered to be "too weak and delicate" to run such a "long" distance. In the 1950s when the 800-m run was reintroduced for women in Europe, ambulances were stationed at the finish line, motors running, to carry off the casualties (Ullyot, 1976). In 1963, the women's world marathon record (then not an Olympic sport for women) was 3:37.07, a time now commonly achieved by females not considered to be elite athletes. The women's world best (set in 2003) was 2:15.25, an improvement of 1:21.42 (37.5%).
- In 1954, Kraus and Hirschland published a report indicating that American children were less fit than European children (Kraus and Hirschland, 1954). These results started the physical fitness movement. At that time, being fit was defined as being able to pass the Kraus-Weber test of minimal muscular fitness, which consisted of one each of the following: bent-leg sit-up; straight-leg sit-up; standing toe touch; double-leg lift, prone; double-leg lift, supine; and trunk extension, prone. Today (as is discussed in detail later in this chapter), physical fitness is more broadly defined in terms of both physiology and specificity (health-related and sport-related), and its importance for individuals of all ages is widely recognized.

These changes and a multitude of others that we readily accept as normal have come about as a combined result of formal medical and scientific research and informal experimentation by individuals with the curiosity and courage to try new things.

What Is Exercise Physiology and Why Study It?

The events and changes described above exemplify concerns in the broad area of exercise physiology, that is, athletic performance, physical fitness, health, and rehabilitation. **Exercise physiology** can be defined as both a basic and an applied science that describes, explains, and uses the body's response to exercise and adaptation to exercise training to maximize human physical potential.

No single course or textbook, of course, can provide all the information a prospective professional will need. However, knowledge of exercise physiology and an appreciation for practice based on research findings help set professionals in the field apart from mere practitioners. It is one thing to be able to lead yoga routines. It is another to be able to design routines based on predictable short- and long-term responses of given class members, to evaluate those responses, and then to modify the sessions as needed. To become respected professionals in fields related to exercise science and physical education, students need to learn exercise physiology in order to:

1. Understand how the basic physiological functioning of the human body is modified by various types of exercise as well as the mechanisms causing these changes. Unless one knows what responses are normal, one cannot recognize an abnormal response or adjust to it.
2. Understand how the basic physiological functioning of the human body is modified by various training programs and the mechanisms responsible for these changes. Adaptations will be specific to the training program used.
3. Provide quality fitness programming and physical education programs in schools that stimulate children and adolescents both physically and intellectually. To become lifelong exercisers, individuals need to understand how physical activity can benefit them, why they take physical fitness tests, and what to do with fitness test results.
4. Apply the results of scientific research to maximize health, rehabilitation, and/or athletic performance in a variety of subpopulations.
5. Respond accurately to questions and advertising claims, as well as recognize myths and misconceptions regarding exercise. Good advice should be based on scientific evidence.

Overview of the Text

Just as the fitness participant, athlete (**Figure 1.1**), or even musician warms up before working out, competing, or performing, this chapter is intended to provide you, the learner, with an essential warm-up for the rest of the text. That is, it provides the basic information that will prepare you to successfully understand what follows in the text and accomplish the goals stated above. To do this, the textbook is first divided into four units: metabolic system, cardiovascular-respiratory system, neuromuscular-skeletal system, and neuroendocrine-immune system. To facilitate learning, each unit follows a consistent format:

1. Basic information
   a. Anatomical structures
   b. Physiological function
   c. Laboratory techniques and variables typically measured
2. Exercise responses
3. Training
   a. Application of the training principles
   b. Adaptations to training
4. Special applications, problems, and considerations

Each unit first deals with basic anatomical structures and physiological functions necessary to understand the material that follows. Then each unit describes the acute responses to exercise. Following are specific applications of the training principles and discussion of the typical adaptations that occur when the training principles are applied correctly. Finally, each unit ends with one or more special application topics, such as thermal concerns, weight control/body composition, and osteoporosis. This integrated approach demonstrates the relevance of applying basic information.

FIGURE 1.1 Warming up in Preparation for Performance.

More exercise physiology research has been done on college-age males and elite male athletes than on any other portion of the population. Nonetheless, wherever possible, we provide information about both sexes as well as children and adolescents at one end of the age spectrum and older adults at the other, throughout the unit.

Each unit is independent of the other three, although the body obviously functions as a whole. Your course, therefore, may sequence these units of study in a different order other than just going from Chapter 1 to Chapter 22. After this first chapter, your instructor may start with any unit and then move in any order through the other two. This concept is represented by the circle in (**Figure 1.2**).

Figure 1.2 also illustrates two other important points: (1) all of the systems respond to exercise in an integrated fashion, and (2) the responses of the systems are interdependent. The metabolic system produces cellular energy in the form of adenosine triphosphate (ATP). ATP is used for muscular contraction. For the cells (including muscle cells) to produce ATP, they must be supplied with oxygen and fuel (foodstuffs). The respiratory system brings oxygen into the body via the lungs, and the cardiovascular system distributes oxygen and nutrients to the cells of the body via the blood pumped by the heart through the blood vessels. During exercise, all these functions must increase. The neuroendocrine-immune system regulates and integrates both resting and exercise body functions.

Each unit is divided into multiple chapters depending on the amount and depth of the material. Each chapter begins with a list of learning objectives that present an

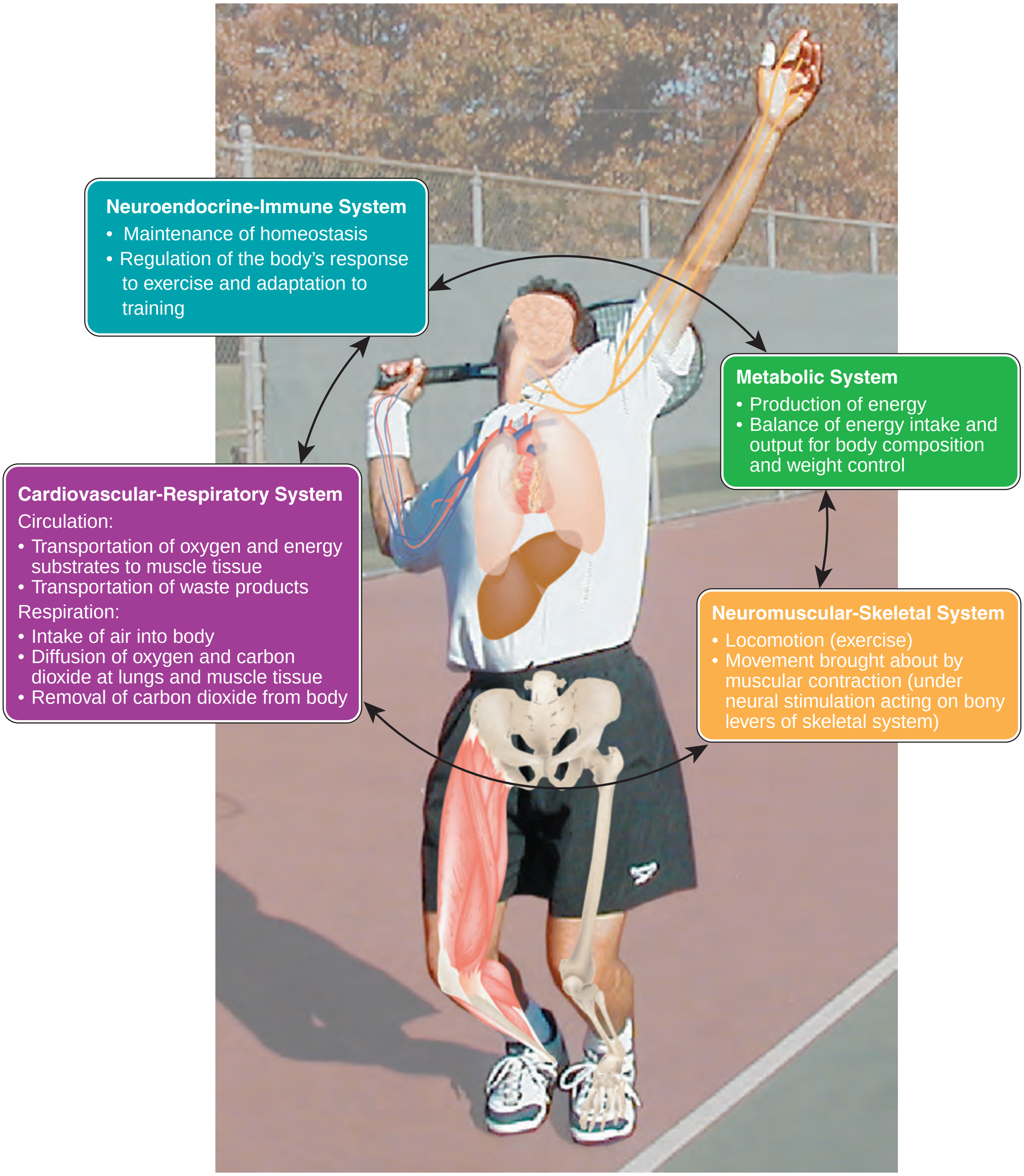

FIGURE 1.2 Schematic Representation of Text Organization.

overall picture of chapter content and help you understand what you should learn. Definitions are highlighted and boxed as they are introduced. Each chapter ends with a summary and review questions. Appearing throughout the text are Focus on Research and Focus on Application boxes, which present four types of research studies:

1. Analytical—an evaluation of available information in a review
2. Descriptive—a presentation of some variable (such as heart rate or blood lactate) or population (such as children or highly trained endurance athletes)
3. Experimental—a design in which treatments have been manipulated to determine their effects on selected variables
4. Quasi-experimental—designs such as used in epidemiology that study the frequency, distribution, and risk of disease among population subgroups in real-world settings

Focus on Research boxes present classic, illustrative, or cutting-edge research findings. Focus on Application boxes show how research may be used in practical contexts. Some of each type of focus box have been designated as Clinically Relevant.

Clinically Relevant boxes present information, situations, or case studies related to clinical experiences students of exercise physiology often have. These include selected topics in athletic training, cardiac or other rehabilitation, coaching, personal training, physical therapy, and/or teaching. An additional feature is the Check Your Comprehension box. The Check Your Comprehension boxes are problems for you to complete. Occasionally the Check Your Comprehension boxes will be clinically relevant. Answers to these problems are presented in Appendix C. When appropriate, calculations are worked out in examples. The appendices and endpapers provide supplemental information. For example, Appendix A contains a listing of the basic physical quantities, units of measurement, and conversions within the Système International d'Unités (SI or metric system of measurement commonly used in scientific work) and between the metric and English measurement systems. In the front of the book, you will find a list of the symbols and abbreviations used throughout the book, along with their full names. You may need to refer to these appendices/endpapers frequently if these symbols and measurement units are new to you.

Exercise physiology is a dynamic area of study with many practical implications. Over the next few months, you will gain an appreciation for the tremendous range in which the human body can function. At the same time, you will become better prepared as a professional to carry out your responsibilities in your particular chosen field. Along the way, you will probably also learn things about yourself. Enjoy the voyage.

The Exercise Response

Let's begin with some definitions and concepts required for understanding all the units to come. **Exercise** is a single acute bout of bodily exertion or muscular activity that requires an expenditure of energy above resting level and that in most, but not all, cases results in voluntary movement. Exercise sessions are typically planned and structured to improve or maintain one or more components of physical fitness. The term *physical activity*, in contrast, generally connotes movement in which the goal (often to sustain daily living or recreation) is different from that of exercise, but which also requires the expenditure of energy and often provides health benefits. For example, walking to school or work is physical activity, while walking around a track at a predetermined heart rate is exercise. Exercise is sometimes considered a subset of physical activity with a more specific focus (Caspersen et al., 1985). From a physiological standpoint, both involve the process of muscle action/energy expenditure and bring about changes (acute and chronic). Therefore, the terms exercise and physical activity are often used interchangeably in this textbook. Where the amount of exercise can actually be measured, the terms workload or work rate may be used as well.

Homeostasis is the state of dynamic equilibrium (balance) of the body's internal environment. Exercise disrupts homeostasis, causing changes that represent the body's response to exercise. An **exercise response** is the pattern of change in physiological variables during a single acute bout of physical exertion. A physiological *variable* is any measurable bodily function that changes or *varies* under different circumstances. For example, heart rate is a variable with which you are undoubtedly already familiar. You probably also know that heart rate increases during exercise. However, to state simply that heart rate increases during exercise does not describe the full pattern of the response. For example, the heart rate response to a 400-m sprint is different from the heart rate response to a 50-mi bike ride. To fully understand the response of heart rate or any other variable, we need more information about the exercise itself. Three factors are considered when determining the acute response to exercise:

1. The exercise modality
2. The exercise intensity
3. The exercise duration

Exercise Modality

Exercise modality (or **mode**) means the type of activity or the particular sport. For example, rowing has a very different effect on the cardiovascular-respiratory system than does football. Modalities are often classified by the type of energy demand (aerobic or anaerobic), the major muscle action (continuous and rhythmical, dynamic resistance, or static), or a combination of the energy system and muscle action. Walking, cycling, and swimming are examples of continuous, rhythmical aerobic activities; jumping, sprinting, and weight lifting are anaerobic and/or dynamic resistance activities. To determine the effects

Exercise A single acute bout of bodily exertion or muscular activity that requires an expenditure of energy above resting level and that in most, but not all, cases results in voluntary movement.

Homeostasis The state of dynamic equilibrium (balance) of the internal environment of the body.

Exercise Response The pattern of homeostatic disruption or change in physiological variables during a single acute bout of physical exertion.

Exercise Modality or Mode The type of activity or sport; usually classified by energy demand or type of muscle action.

TABLE 1.1 Absolute and Relative Submaximal Workloads

	Absolute Workload		Relative Workload	
	Maximal Lift	No. of Times 80 lb Can Be Lifted	75% of Maximal Lift	No. of Times 75% Can Be Lifted
Gerry	160	12	120	10
Pat	100	6	75	10
Terry	80	1	60	10

of exercise on a particular variable, you must first know what type of exercise is being performed.

Exercise Intensity

Exercise intensity is most easily described as maximal or submaximal. **Maximal (max) exercise** is straightforward; it simply refers to the highest intensity, greatest load, or longest duration an individual is capable of doing. Motivation plays a large part in the achievement of maximal levels of exercise. Most maximal values are reached at the endpoint of an *incremental exercise test to maximum*; that is, the exercise task begins at a level the individual is comfortable with and gradually increases until he or she can do no more. The values of the physiological variables measured at this time are labeled as "max"; for example, maximum heart rate is symbolized as HRmax.

Submaximal exercise may be described in one of two ways. The first involves a *set load*, which is a load that is known or is assumed to be below an individual's maximum. This load may be established by some physiological variable, such as working at a specific heart rate (perhaps 150 $b \cdot min^{-1}$); at a specific work rate (e.g., 600 $kgm \cdot min^{-1}$ on a cycle ergometer); or for a given distance (perhaps a 1-mi run). Such a load is called an **absolute workload**. If an absolute workload is used, and the individuals being tested vary in fitness, then some individuals will be challenged more than others. Generally, those who are more fit in terms of the component being tested will be less challenged and so will score better than those who are less fit and more challenged. For example, suppose the exercise task is to lift 80 lb in a bench press as many times as possible, as in the YMCA bench press endurance test. As illustrated in **Table 1.1**, if the individuals tested were able to lift a maximum of 160, 100, and 80 lb once, respectively, it would be anticipated that the first individual could do more repetitions of the 80-lb lift than anyone else. Similarly, the second individual would be expected to do more repetitions than the third, and the third individual would be expected to do only one repetition. In this case the load is not submaximal for all the individuals, because Terry can lift the weight only one time (making it a maximal lift for Terry). Nonetheless, the use of an absolute load allows for the ranking of individuals based on the results of a single exercise test and is therefore often used in physical fitness screenings or tests.

The second way to describe submaximal exercise is as a percentage of an individual's maximum. A load may be set at a percentage of the person's maximal heart rate, maximal ability to use oxygen, or maximal workload. This value is called a **relative workload** because it is prorated or relative to each individual. All individuals are therefore expected to be equally challenged by the same percentage of their maximal task. This should allow the same amount of time or number of repetitions to be completed by most, if not all, individuals. For example, for the individuals described in **Table 1.1**, suppose that the task now is to lift 75% of each one's maximal load as many times as possible. The individuals will be lifting 120, 75, and 60 lb, respectively. If all three are equally motivated, they should all be able to perform the same total number of repetitions. Relative workloads are occasionally used in physical fitness testing. They are more frequently used to describe exercises that are light, moderate, or heavy in intensity or to prescribe exercise guidelines.

There is no universal agreement about what exactly constitutes light, moderate, or heavy intensity. In general, this book uses the following classifications:

1. Low or light: ≤54% of maximum
2. Moderate: 55–69% of maximum
3. Hard or heavy: 70–89% of maximum
4. Very hard or very heavy: 90–99% of maximum
5. Maximal: 100% of maximum
6. Supramaximal: >100% of maximum

Maximal (max) Exercise The highest intensity, greatest load, or longest duration exercise of which an individual is capable.

Absolute Submaximal Workload A set exercise load performed at any intensity from just above resting to just below maximum.

Relative Submaximal Workload A workload above resting but below maximum that is prorated to each individual; typically set as some percentage of maximum.

Maximal Voluntary Contraction (MVC) The maximal force that the muscle can exert.

1-RM The maximal weight that an individual can lift once during a dynamic resistance exercise.

Maximum is defined variously in terms of workload or work rate, heart rate, oxygen consumption, weight lifted for a specific number of repetitions, or force exerted in a voluntary contraction. Specific studies may use percentages and definitions of maximum that vary slightly.

Exercise Duration

Exercise duration is simply a description of the length of time the muscular action continues. Duration may be as short as 1–3 seconds for an explosive action, such as a jump, or as long as 12 hours for a full triathlon (3.2-km [2-mi] swim, 160-km [100-mi] bicycle ride, and 42.2-km [26.2-mi] run). In general, the shorter the duration, the higher the intensity that can be used. Conversely, the longer the duration, the lower the intensity that can be sustained. Thus, the amount of homeostatic disruption depends on both the duration and intensity of the exercise.

Exercise Categories

This textbook combines the descriptors of exercise modality, intensity, and duration into six primary categories of exercise. Where sufficient information is available, the exercise response patterns for each are described and discussed:

1. *Short-term, light to moderate submaximal aerobic exercise*. Exercises of this type are rhythmical and continuous in nature and utilize aerobic energy. They are performed at a constant workload for 10–15 minutes at approximately 30–69% of maximal work capacity.
2. *Long-term, moderate to heavy submaximal aerobic exercise*. Exercises in this category also utilize rhythmical and continuous muscle action. Although predominantly aerobic, anaerobic energy utilization may be involved. The duration is generally between 30 minutes and 4 hours at constant workload intensities ranging from 55 to 89% of maximum.
3. *Incremental aerobic exercise to maximum*. Incremental exercises start at light loads and continue by a predetermined sequence of progressively increasing workloads to an intensity that the exerciser cannot sustain or increase further. This point becomes the maximum (100%). The early stages are generally light and aerobic, but as the exercise bout continues, anaerobic energy involvement becomes significant. Each workload/work rate is called a stage, and each stage may last from 1 to 10 minutes, although 3 minutes is most common. Incremental exercise bouts typically last between 5 and 20 minutes for the total duration.
4. *Static exercise*. Static exercises involve muscle contractions that produce an increase in muscle tension and energy expenditure but do not result in meaningful movement. Static contractions are measured as some percentage of the muscle's **maximal voluntary contraction (MVC)**, the maximal force that the muscle can exert. The intent is for the workload to remain constant, but fatigue sometimes makes that impossible. The duration is inversely related to the percentage of maximal voluntary contraction (%MVC) that is being held, but generally ranges from 2 to 10 minutes.
5. *Dynamic resistance exercise*. These exercises utilize muscle contractions that exert sufficient force to overcome the presented resistance, so that movement occurs, as in weight lifting. Energy is supplied by both aerobic and anaerobic processes, but anaerobic is dominant. The workload is constant and is based on some percentage of the maximal weight the individual can lift **(1-RM)** or a resistance that can be lifted for a specified number of times. The number of repetitions, not time, is the measure of duration.
6. *Very-short-term, high-intensity anaerobic exercise*. Activities of this type last from a few seconds to approximately 3 minutes. They depend on high-power anaerobic energy and are often supramaximal.

Complete the Check Your Comprehension 1 box.

CHECK YOUR COMPREHENSION 1

Describe each of the following activities using the terms of the six exercise response categories.

1. A male cheerleader holds a female cheerleader overhead.
2. A body builder poses.
3. A new mother pushes her baby in a stroller in the park for 20 minutes.
4. A freshman in high school takes the FITNESSGRAM® PACER (Progressive Aerobic Cardiovascular Endurance Run) test in physical education class.
5. An adult male completes a minitriathlon in 2:35.
6. A basketball player executes a fast break ending with a slam dunk.
7. A volleyball player performs two sets of six squats.
8. A cyclist completes a 25-mi time trial in 50:30.6
9. An exercise physiology student completes a graded exercise test on a cycle ergometer with 3-minute stages and + 50 kgm·min^{-1} per stage to determine $\dot{V}O_2$max.
10. A barrel racer warms up her horse for 15 minutes prior to competition.
11. A middle-aged individual performs 18 repetitions in the YMCA bench press endurance test.
12. A college athlete participates in a 400-m track race.

Check your answers in Appendix C.

Exercise Response Patterns

Throughout the textbook, the exercise response patterns for the six categories of exercise are described verbally and depicted graphically. For ease of recognition, consistent background colors and icons represent each category of exercise (**Table 1.2**). **Figure 1.3** presents six of the most frequent graphic patterns resulting from a constant workload/work rate, that is, all of the exercise categories except incremental exercise to maximum and very-short-term, high-intensity anaerobic exercise. Frequent incremental exercise patterns are depicted in **Figure 1.4**. The verbal descriptors used throughout the book are included on these graphs and in the following paragraphs. Note that the y-axis can be any variable that is measured with its appropriate unit of measurement. Examples are heart rate (b·min^{-1}), blood pressure (mmHg), and oxygen consumption (mL·kg·min^{-1}). Only specific graphic patterns are applicable to any given variable. These combinations of pattern and variable are described in the exercise response sections in each unit. Although not indicated in the figure, curvilinear changes can also be described as exponential—either positive or negative. For each exercise response, the baseline, or starting point against which the changes are compared, is the variable's resting value. Your goal here is to become familiar with the graphic patterns and the terminology used to describe each.

The patterns showing an initial increase or decrease with a plateau at steady state (**Figure 1.3A** and **B**) are the most common responses to short-term, light to moderate submaximal aerobic exercise. Patterns that include a drift seen as the gradual curvilinear increase or decrease from a plateau despite no change in the external workload (**Figure 1.3C** and **D**), typically result from

TABLE 1.2 Color and Icon Interpretation for Exercise Response Patterns

Exercise Category	Color	Icon
Short-term, light to moderate submaximal aerobic		
Long-term, moderate to heavy submaximal aerobic		
Incremental aerobic to maximum		
Static		
Dynamic resistance		
Very short-term, high-intensity anaerobic		

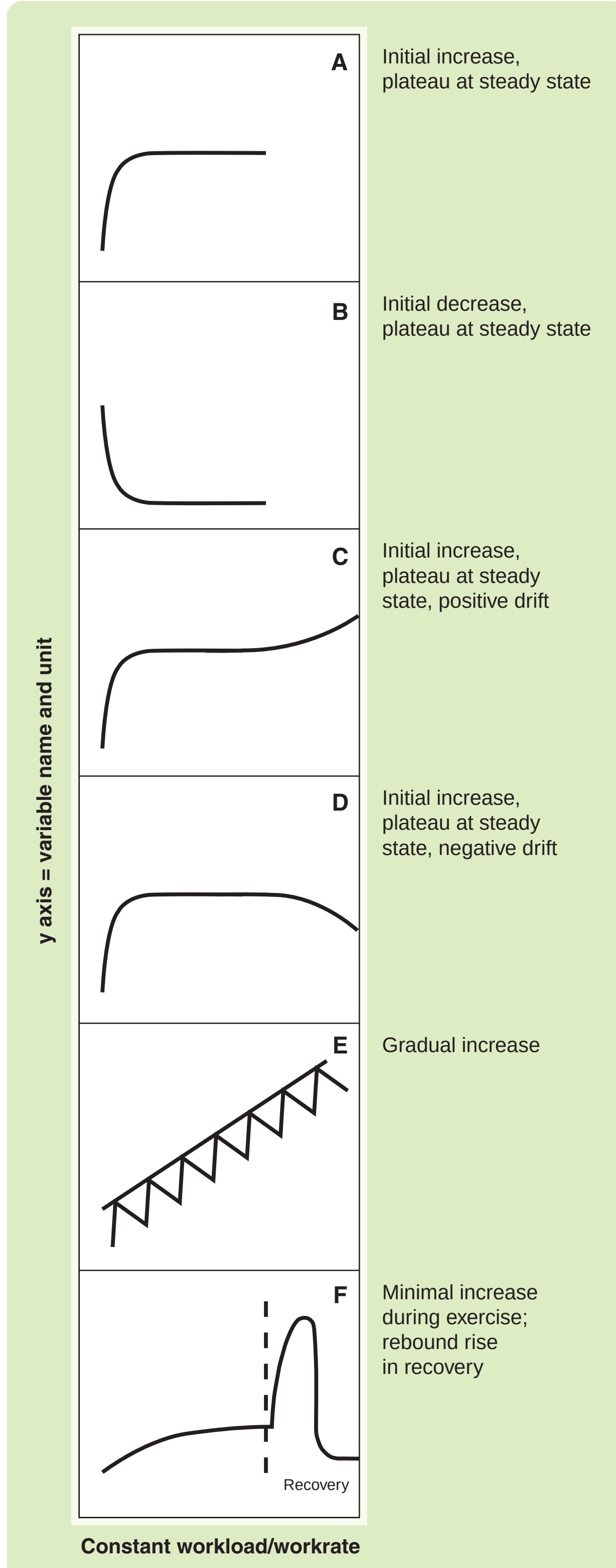

FIGURE 1.3 Graphic Patterns and Verbal Descriptors for Constant Workload/Work Rate Exercise Responses.

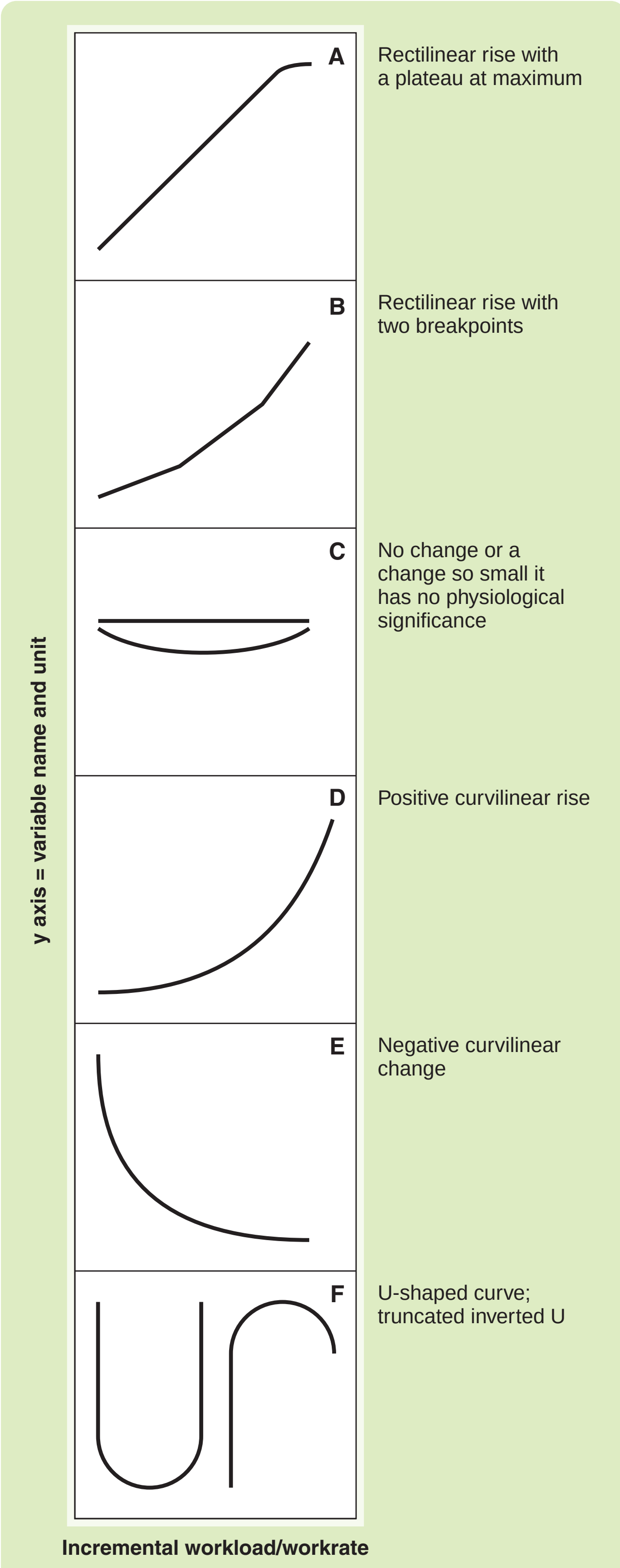

FIGURE 1.4 Graphic Patterns and Verbal Descriptors for Incremental Workload/Work Rate Exercise Responses.

long-term, moderate to heavy submaximal aerobic exercise. Another form of gradual increase despite no change in the external workload (**Figure 1.3E**), is frequently seen during dynamic resistance exercise as a saw tooth pattern resulting from the sequential lifting and lowering of the weight. Finally, some categories of exercise may show a smooth, gradual increase (the straight rising line of **Figure 1.3E**). Minimal change during exercise with a rebound rise in recovery is almost exclusively a static exercise response (**Figure 1.3F**).

As the title of **Figure 1.4** indicates, all of these patterns of response routinely result from incremental exercise to maximum. Panel **1.4F** shows two versions of the U-shaped pattern. You may see either a complete or truncated (shortened) U, either upright or inverted. No specific patterns are shown for very-short-term, high-intensity anaerobic exercise, because these tend to be either abrupt rectilinear or curvilinear increases or decreases.

Exercise Response Interpretation

When interpreting the response of variables to any of the exercise categories, keep four factors in mind:

1. Characteristics of the exerciser
2. Appropriateness of the selected exercise
3. Accuracy of the selected exercise
4. Environmental and experimental conditions

Characteristics of the Exerciser

Certain characteristics of the exerciser can affect the magnitude of the exercise response. The basic pattern of the response is similar, but the magnitude of the response may vary with the individual's sex, age (child/adolescent, adult, older adult), and/or physiological status, such as health and training level. Where possible, these differences will be pointed out. See the Focus on Research Box for an example.

Appropriateness of the Selected Exercise

The exercise test used should match the physiological system or physical fitness component one is evaluating. For example, you cannot determine cardiovascular endurance using dynamic resistance exercise. However, if the goal is to determine how selected cardiovascular variables respond to dynamic resistance exercise, then, obviously, that is the type of exercise that must be used.

The modality used within the exercise category should also match the intended outcome. For example, if the goal is to demonstrate changes in cardiovascular-respiratory fitness for individuals training on a stationary cycle, then an incremental aerobic exercise to maximum test should be conducted on a cycle ergometer, not a treadmill or other piece of equipment.