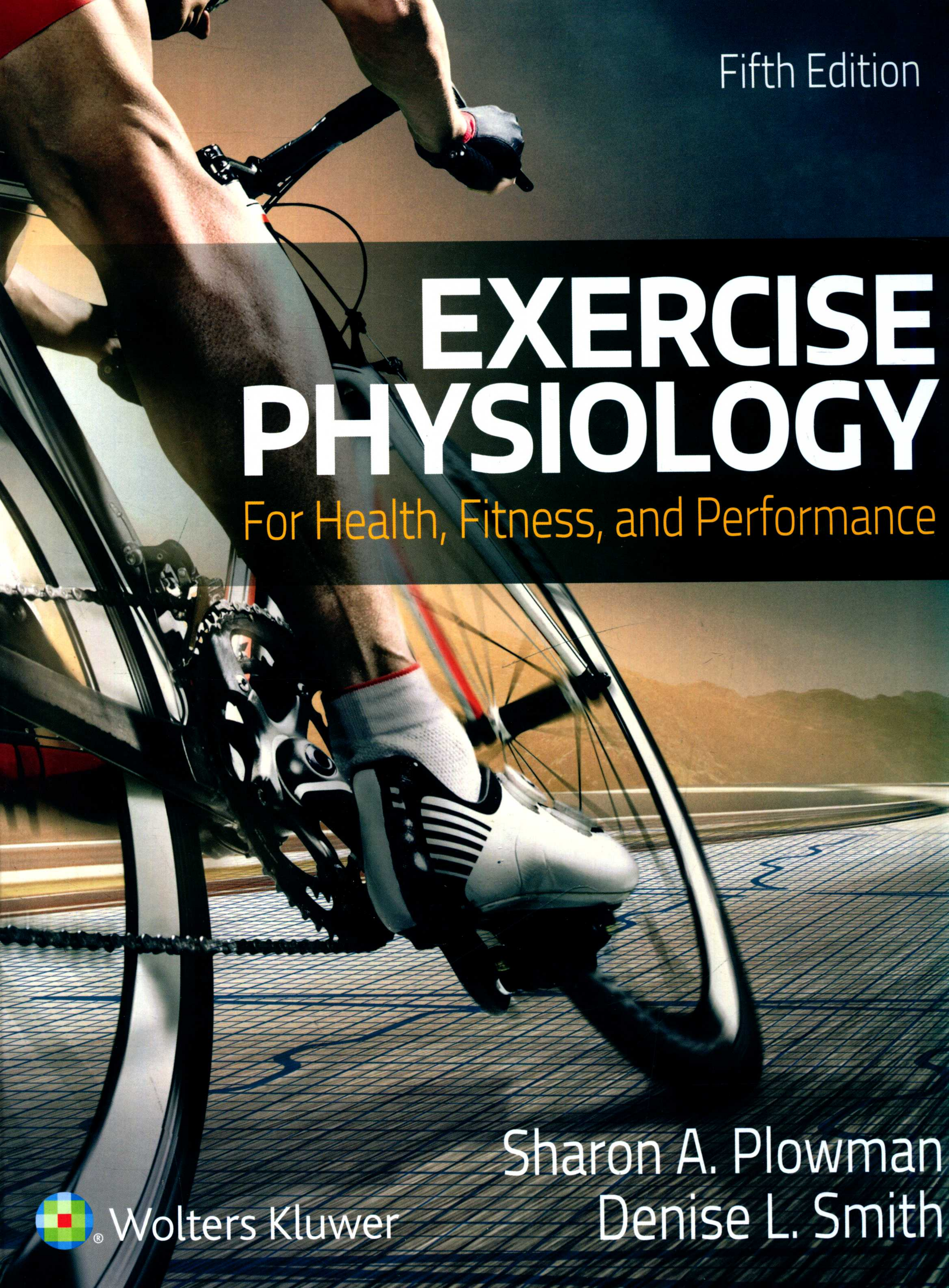
Fifth Edition

EXERCISE PHYSIOLOGY

For Health, Fitness, and Performance



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Wolters Kluwer

Exercise Physiology

FOR HEALTH, FITNESS, AND PERFORMANCE

Fifth Edition

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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
O_2	oxygen
OBLA	onset of blood lactate accumulation
OI	osteogenic index
OP	oxidative phosphorylation
OR	overreaching
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
pQCT	peripheral quantitative computed tomography
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
RED-S	relative energy deficiency in sport
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 lipoprotein
$\dot{V}O_2$	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 exercise 

Long-term, moderate to heavy submaximal aerobic exercise 

Incremental aerobic to maximum exercise 

Static exercise 

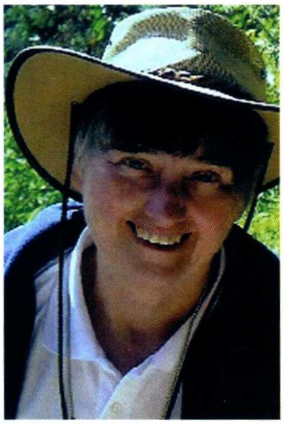
Dynamic resistance exercise 

Very short-term, high-intensity anaerobic exercise 

Dedication

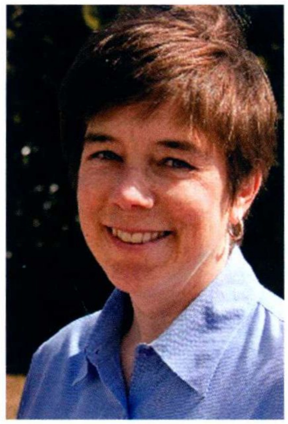
To our teachers and students,
past, present, and future:
sometimes one and the same.

About the Authors



SHARON A. PLOWMAN earned her PhD 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 75 scientific research articles in exercise physiology and applied articles on physical fitness with emphasis on accurate and appropriate test items, 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), has published several chapters in other books, and is coeditor of the 2013 *FitnessGram® Reference Guide*.

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 as an Active Fellow by the American Academy of Kinesiology and Physical Education (National Academy of Kinesiology). She serves on the Advisory Council for FitnessGram®, the assessment tool for the Presidential Youth Fitness Program. The American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD) (now the Society of Health and Physical Educators [SHAPE]) 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 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 PhD in kinesiology and specialization in exercise physiology from the University of Illinois at Urbana–Champaign, Dr. Smith has taught for over 25 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 responses to firefighting. Dr. Smith has received more than $10 million in research funding and has published over 70 peer-reviewed articles in such journals as *American Journal of Cardiology*, *Cardiology in Review*, *Medicine & Science in Sports & Exercise*, *Exercise and Sport Sciences Reviews*, *Vascular Medicine*, *Ergonomics*, *European Journal of Applied Physiology*, *Journal of Applied Physiology*, and *Occupational Medicine*. 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 also 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 fifth edition of *Exercise Physiology for Health, Fitness, and Performance* builds upon and expands the strength of the first four editions. The purpose of the current edition, however, remains unchanged. 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, 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, exercise science, and allied health 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, older adults in special programs, and both sexes of all ages in allied health settings. 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 learning about.

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 presented in definition boxes as they are introduced and are colored in bold type 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 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. Figure and table numbers are highlighted in color in the text to identify the relevant textual material instantly.

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**. Population comparisons (male-female, children/adolescents-adults, trained-untrained) are also color coded on graphs where applicable.

Active Learning

Throughout the text, **Check Your Comprehension** and **Check Your Comprehension-Case Study** boxes engage the student in active learning beyond just reading. The number of these has been expanded for this edition at faculty request. 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 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/ Check Your Comprehension-Case Study 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*, Fifth Edition.

For Students

- Crossword puzzles using key terms and definitions. Answers are accessible.
- Quiz bank of multiple choice questions intended 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 calculations 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
- Laboratory manual
- Answers to in-text chapter review questions

User's Guide

This User's Guide explains the key features found in the fifth 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.

Commonly Used Symbols and Abbreviations

$(A\text{-}a)PO_2$diff	difference between partial pressure of oxygen in alveoli and arterial blood	ESV	end systolic volume
$a\text{-}\bar{v}O_2$diff	difference in oxygen content between arterial and venous blood	ETAP	exercise-related transient abdominal pain
A	actin	ETS	electron transport system
ACh	acetylcholine	F_ECO_2	fraction of expired carbon dioxide
ACTH	adrenocorticotrophic hormone	F_EN_2	fraction of expired nitrogen
ADH	antidiuretic hormone	F_EO_2	fraction of expired oxygen
ADL	activities of daily living	F_G	fraction of a gas
ADP	adenosine diphosphate	F_ICO_2	fraction of inspired carbon dioxide
AI	adequate intake	F_IN_2	fraction of inspired nitrogen
AIDS	acquired immune deficiency syndrome	F_IO_2	fraction of inspired oxygen
AMP	adenosine monophosphate	f	frequency
AN	anorexia nervosa	FAD	flavin adenine dinucleotide
ANS	autonomic nervous system	FEV	forced expiratory volume
AP	action potential	FFA	free fatty acids
ATP	adenosine triphosphate	FFB	fat-free body mass
ATP-PC	phosphagen system	FFM	fat-free mass
ATPS	atmospheric temperature and pressure, saturated air	FFW	fat-free weight
AV	atrioventricular	FG	fast twitch, glycolytic muscle fibers
BCAA	branched chain amino acids	FI	fatigue index
BED	binge eating disorder	FOG	fast twitch, oxidative-glycolytic muscle fibers
BF	body fat	FT	fast twitch muscle fibers
BMC	bone mineral content	GAS	General Adaptation Syndrome
BMD	bone mineral density	GH	growth hormone
		GI	glycemic index
		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_b	mass of the body in the air

OBJECTIVES

After studying the chapter, you should be able to:

- Distinguish among and explain the component variables of pulmonary ventilation, external respiration, and internal respiration.
- Identify the conductive and respiratory zones of the respiratory system and compare the functions of the two zones.
- Explain the mechanics of breathing.
- Differentiate between pulmonary circulation and bronchial circulation.
- Describe static and dynamic lung volumes.
- Distinguish between the conditions under which respiratory measures are collected and reported.
- Calculate minute and alveolar ventilation, the partial pressure of a gas in a mixture, the amount of oxygen carried per deciliter of blood, and the arteriovenous oxygen difference.
- Explain how respiration is regulated at rest and during exercise.
- Explain how oxygen and carbon dioxide are transported in the circulatory system and how oxygen is released to the tissues.
- Explain the role of respiration in acid-base balance.

Chapter Objectives

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

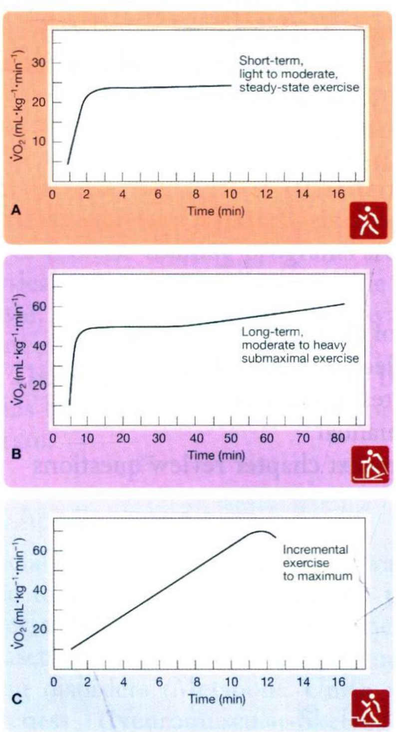


FIGURE 4.4 **Oxygen Consumption Responses to Various Exercises.**
A. Short-term, light to moderate, submaximal aerobic exercise. **B.** Long-term, moderate to heavy, submaximal dynamic aerobic exercise. **C.** Incremental aerobic exercise to maximum.

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.

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		

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 RESEARCH ***Clinically Relevant***

Live High, Train Low

This study was designed to test the hypothesis that acclimation to living at moderate altitude (2,500 m, 8,260 ft) combined with training at low altitude (1,250 m, 4,125 ft) (high-low condition) would improve sea-level (5,000 m, 3.1 mi) performance in already well-conditioned athletes more than

only 6% compared with the sea-level group, whereas that of the high-altitude training group was reduced by 18.5%. Both groups that lived at moderate altitude significantly increased red blood cell mass by 9% and $\dot{V}O_2$max by 5%, while the sea-level group showed neither change. Arteriovenous oxygen

oth

m

ing.

altitude training is possible if athletes live at moderate altitude but train at lower levels that permit maintaining a high training intensity.

Source: Levine, B. D., & J. Stray-Gundersen: "Living high—training low": Effect of moderate-altitude acclimatization with low-altitude training on performance. *Journal of Applied Physiology*. 83(1):102–112 (1997).

nended. The altitude should be at least n 2,100 and 2,500 m (~6,700–8,200 ft) but in 3,000 m (~9,800 ft) while training should ace at ≤1,250 m (~4,100 ft or less). If circum- require it, simulated altitude can be used.

ic exposure should be greater than 12 hr·d^{-1}, eferably 16 hr·d^{-1}.

ig should last at least 3–4 weeks.

ntensity training must be maintained as if were not involved.

st time to return from altitude training prior competition for peak performance remains to ned. Conventional wisdom includes several tive to performance expectations: (1) return n initial improvement; (2) days 3–14, decre- erformance and reduced training capability; –20, a high plateau in performance; and (4) , possible benefits. Even given the overlap- the best timing may ultimately depend upon responses. Athletes who exhibit a high level ry acclimatization or mechanical limitations ry flow may need a period of sea-level train- competition; athletes with a faster than nor- in RBC mass may need to compete as soon upon return from altitude. Individual varia- response to altitude training is not yet fully

Focus on Application Boxes

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

FOCUS ON APPLICATION ***Clinically Relevant***

Decreased PCO_2 and Drowning

The decrement in PCO_2 with hyperventilation can have serious consequences. Many people know that hyperventilating can extend breath-holding time but erroneously believe it does so because more oxygen is taken in. They are unaware that it is not O_2 but CO_2 levels that are changing (being blown off) and that respiration is more sensitive to PCO_2 changes than to PO_2 changes. Craig (1976) summarized 58 cases of loss of consciousness during underwater swimming and diving following hyperventilation. Of these 58 cases, 23 (40%) ended as fatalities, with most occurring in guarded pools. Because an individual continues patterned motor activity (swimming) for a short time after loss of consciousness caused by a lack of oxygen to the brain, these life-threatening cases are difficult for a lifeguard to detect quickly. Beginning swimmers frustrated by trying to coordinate their arms, legs, and breathing who simply put their head in the water and try to go as far as possible without breathing are also vulnerable. As a result of these findings, it is recommended that underwater swimming be limited to one length of a standard 25-yd or 25-m pool.

Source: Craig (1976).

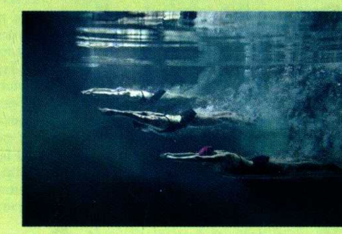


Figure 9.9 earlier schematically depicted factors that control the rate and depth of ventilation. It would be logical to assume that changes in the arterial PO_2 and PCO_2 occur during exercise and have the primary role in control. However, this is not what happens. Neither PO_2 nor PCO_2 changes enough, especially early in exercise or at low to moderate to heavy intensities in untrained individuals, to play a major role in ventilatory control during exercise. Exactly which factor is most important is not known precisely. Changes may take place in the sensitivity of the medullary respiratory control centers themselves during exercise. Neural messages from the motor cortex, muscle proprioceptors, and hypothalamic sympathetic nervous system activity, as well as increases in the hydrogen ion and potassium ion concentrations, all appear to have a role during exercise (Eldridge, 1994; West, 2005).

mitochondria for the production of ATP. Thus, any of the following systems may limit $\dot{V}O_2$max:

1. The respiratory system, because of inadequate ventilation, oxygen diffusion limitations, or an inability to maintain the gradient for the diffusion of O_2 (a-vO_2diff)
2. The cardiovascular system, because of inadequate blood flow ($\dot{Q}$) or oxygen-carrying capacity (Hb)
3. The metabolic functions within skeletal muscle, such as an inability to produce additional ATP because of limited number of mitochondria, limited enzyme levels or activity, or limited substrates

Evidence suggests that each of these systems may limit $\dot{V}O_2$max in certain conditions (Bergh et al., 2000). For example, a reduction in the partial pressure of oxygen (PO_2) at altitude or with asthma causes a reduction in $\dot{V}O_2$max. Medications (such as beta-blockers) that limit cardiac output also cause a decrease in $\dot{V}O_2$max, as does a reduction in hemoglobin associated with anemia. Certain diseases in which muscle enzymes involved in metabolism are deficient can also result in reduced $\dot{V}O_2$max.

Although factors in each of these systems may limit $\dot{V}O_2$max, the question remains: What limits $\dot{V}O_2$max in healthy humans performing maximal exercise? This question has energized exercise physiologists for decades, beginning with the work of A. V. Hill in the 1920s, and it continues to engender lively debate among physiologists today (Bassett and Howley, 2000; Bergh et al., 2000; Elliott et al., 2015; Ferretti, 2014; Grassi, 2000; Hale, 2008; Rowland, 2013; Saltin, 1985).

Current research suggests that maximal oxygen uptake is limited by the ability of the cardiorespiratory system to deliver oxygen to the muscle, rather than the ability of the muscle mitochondria to utilize oxygen (Bergh et al., 2000; Elliott et al., 2015; Hale, 2008; Rowell, 1993; Saltin, 1985). Specifically, cardiac output appears to be the limiting factor in $\dot{V}O_2$max (Bergh et al., 2000; di Prampero, 2003; Saltin, 1985).

Research evidence suggests that oxygen uptake is not limited by pulmonary ventilation in normal, healthy athletes without exercise-induced arterial hypoxemia (Chapter 10). Generally, the functional capacity of the respiratory system is believed to exceed the demands of maximal exercise (Rowell, 1993). The only respiratory or cardiovascular variable likely to impose a limitation on oxygen transport is a-vO_2diff.

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.

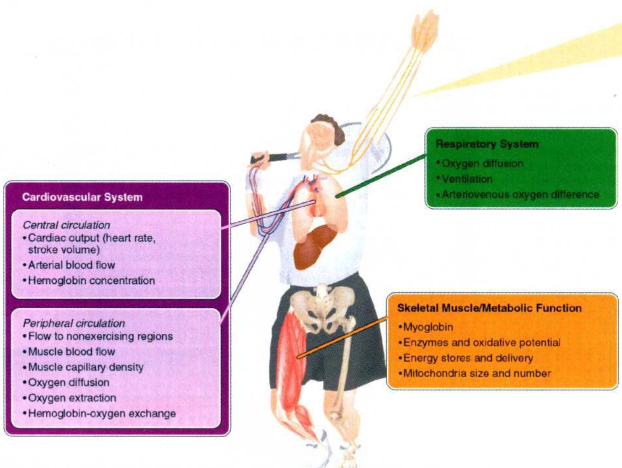


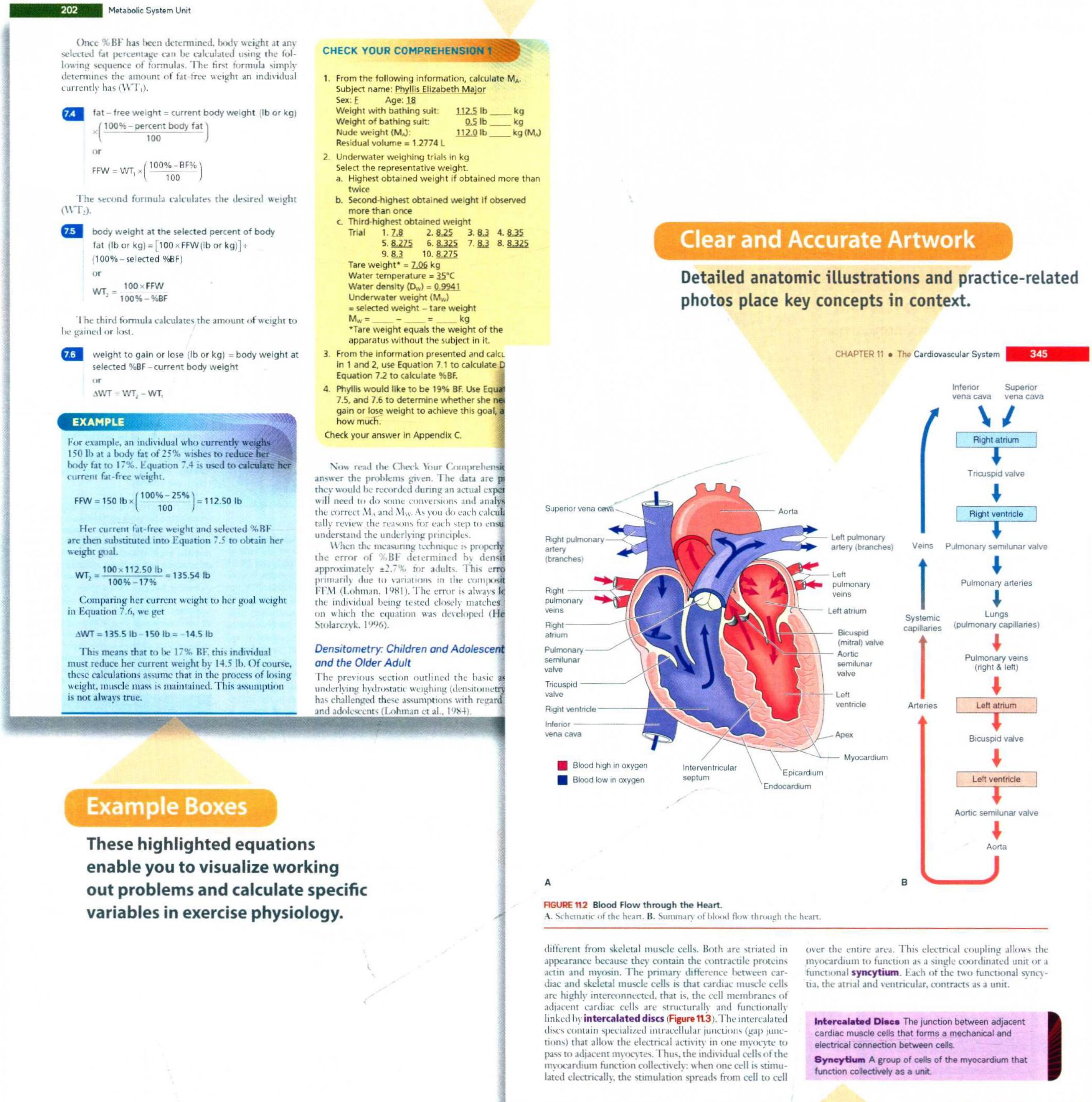
FIGURE 12.10 Possible Limitations to Maximal Oxygen Consumption.
Source: Modified from Rowell (1993).

Check Your Comprehension Boxes

These engaging mini-quizzes challenge you to work through problems, interpret circumstances, analyze information, 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.



202 Metabolic System Unit

Once %BF has been determined, body weight at any selected fat percentage can be calculated using the following sequence of formulas. The first formula simply determines the amount of fat-free weight an individual currently has (WT_1).

7.4 $$\text{fat-free weight} = \text{current body weight (lb or kg)} \times \left(\frac{100\% - \text{percent body fat}}{100}\right)$$ or $$FFW = WT_1 \times \left(\frac{100\% - BF\%}{100}\right)$$

The second formula calculates the desired weight (WT_2).

7.5 $$\text{body weight at the selected percent of body fat (lb or kg)} = [100 \times \text{FFW (lb or kg)}] \div (100\% - \text{selected \%BF})$$ or $$WT_2 = \frac{100 \times FFW}{100\% - \%BF}$$

The third formula calculates the amount of weight to be gained or lost.

7.6 $$\text{weight to gain or lose (lb or kg)} = \text{body weight at selected \%BF} - \text{current body weight}$$ or $$\Delta WT = WT_2 - WT_1$$

EXAMPLE

For example, an individual who currently weighs 150 lb at a body fat of 25% wishes to reduce her body fat to 17%. Equation 7.4 is used to calculate her current fat-free weight.

$$FFW = 150\text{ lb} \times \left(\frac{100\% - 25\%}{100}\right) = 112.50\text{ lb}$$

Her current fat-free weight and selected %BF are then substituted into Equation 7.5 to obtain her weight goal.

$$WT_2 = \frac{100 \times 112.50\text{ lb}}{100\% - 17\%} = 135.54\text{ lb}$$

Comparing her current weight to her goal weight in Equation 7.6, we get

$$\Delta WT = 135.5\text{ lb} - 150\text{ lb} = -14.5\text{ lb}$$

This means that to be 17% BF, this individual must reduce her current weight by 14.5 lb. Of course, these calculations assume that in the process of losing weight, muscle mass is maintained. This assumption is not always true.

CHECK YOUR COMPREHENSION 1

1. From the following information, calculate M_A.
   Subject name: Phyllis Elizabeth Major
   Sex: F Age: 18
   Weight with bathing suit: 112.5 lb ____ kg
   Weight of bathing suit: 0.5 lb ____ kg
   Nude weight (M_A): 112.0 lb ____ kg (M_A)
   Residual volume = 1.2774 L
2. Underwater weighing trials in kg
   Select the representative weight.
   a. Highest obtained weight if obtained more than twice
   b. Second-highest obtained weight if observed more than once
   c. Third-highest obtained weight
   Trial 1. 7.8 2. 8.25 3. 8.3 4. 8.35 5. 8.275 6. 8.325 7. 8.3 8. 8.325 9. 8.3 10. 8.275
   Tare weight* = 7.06 kg
   Water temperature = 35°C
   Water density (D_W) = 0.9941
   Underwater weight (M_W)
   = selected weight − tare weight
   M_W = ____ − ____ = ____ kg
   *Tare weight equals the weight of the apparatus without the subject in it.
3. From the information presented and calcu... in 1 and 2, use Equation 7.1 to calculate D... Equation 7.2 to calculate %BF.
4. Phyllis would like to be 19% BF. Use Equa... 7.5, and 7.6 to determine whether she ne... gain or lose weight to achieve this goal, a... how much.

Check your answer in Appendix C.

Now read the Check Your Comprehensi... answer the problems given. The data are p... they would be recorded during an actual exper... will need to do some conversions and analys... the correct M_A and M_W. As you do each calcul... tally review the reasons for each step to ensu... understand the underlying principles.

When the measuring technique is properly... the error of %BF determined by densi... approximately ±2.7% for adults. This erro... primarily due to variations in the composi... FFM (Lohman, 1981). The error is always l... the individual being tested closely matches... on which the equation was developed (He... Stolarczyk, 1996).

Densitometry: Children and Adolescent... and the Older Adult

The previous section outlined the basic a... underlying hydrostatic weighing (densitometry... has challenged these assumptions with regard... and adolescents (Lohman et al., 1984).

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FIGURE 11.2 Blood Flow through the Heart. A. Schematic of the heart. B. Summary of blood flow through the heart.

different from skeletal muscle cells. Both are striated in appearance because they contain the contractile proteins actin and myosin. The primary difference between cardiac and skeletal muscle cells is that cardiac muscle cells are highly interconnected, that is, the cell membranes of adjacent cardiac cells are structurally and functionally linked by **intercalated discs** (Figure 11.3). The intercalated discs contain specialized intracellular junctions (gap junctions) that allow the electrical activity in one myocyte to pass to adjacent myocytes. Thus, the individual cells of the myocardium function collectively: when one cell is stimulated electrically, the stimulation spreads from cell to cell over the entire area. This electrical coupling allows the myocardium to function as a single coordinated unit or a functional **syncytium**. Each of the two functional syncytia, the atrial and ventricular, contracts as a unit.

Intercalated Discs The junction between adjacent cardiac muscle cells that forms a mechanical and electrical connection between cells.

Syncytium A group of cells of the myocardium that function collectively as a unit.

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

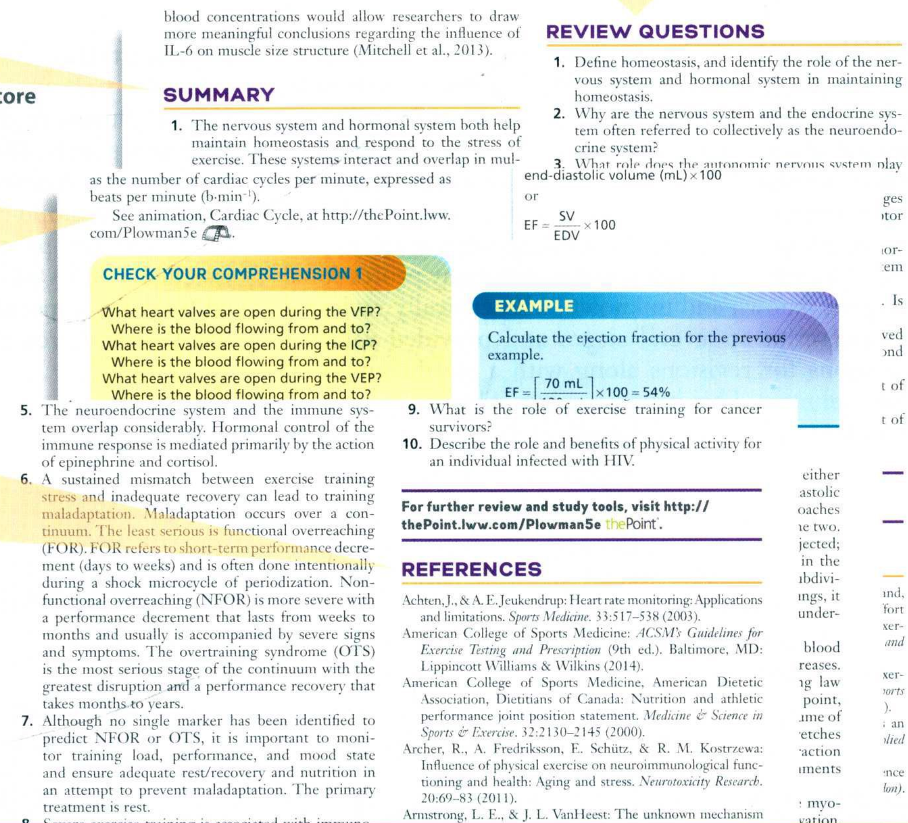
Concise copy points review the chapter's core content.

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.

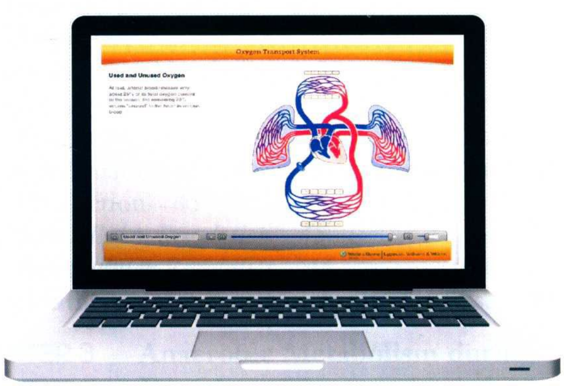


ADDITIONAL LEARNING AND TEACHING RESOURCES

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

thePoint®

http://thePoint.lww.com/Plowman5e



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

Student Resource Center

- Crossword Puzzles: Key Terms and Definitions
  - Matching
  - Calculations
- Quiz Bank Questions
  - Multiple Choice
- Worksheets
  - True/false (with space for corrections)
  - Tables to fill in
- Laboratory Manual
- Answers to Crossword Puzzles, Quiz Bank Questions, and all Worksheets

Faculty Resource Center

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

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Sharon A. Plowman
Denise L. Smith

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