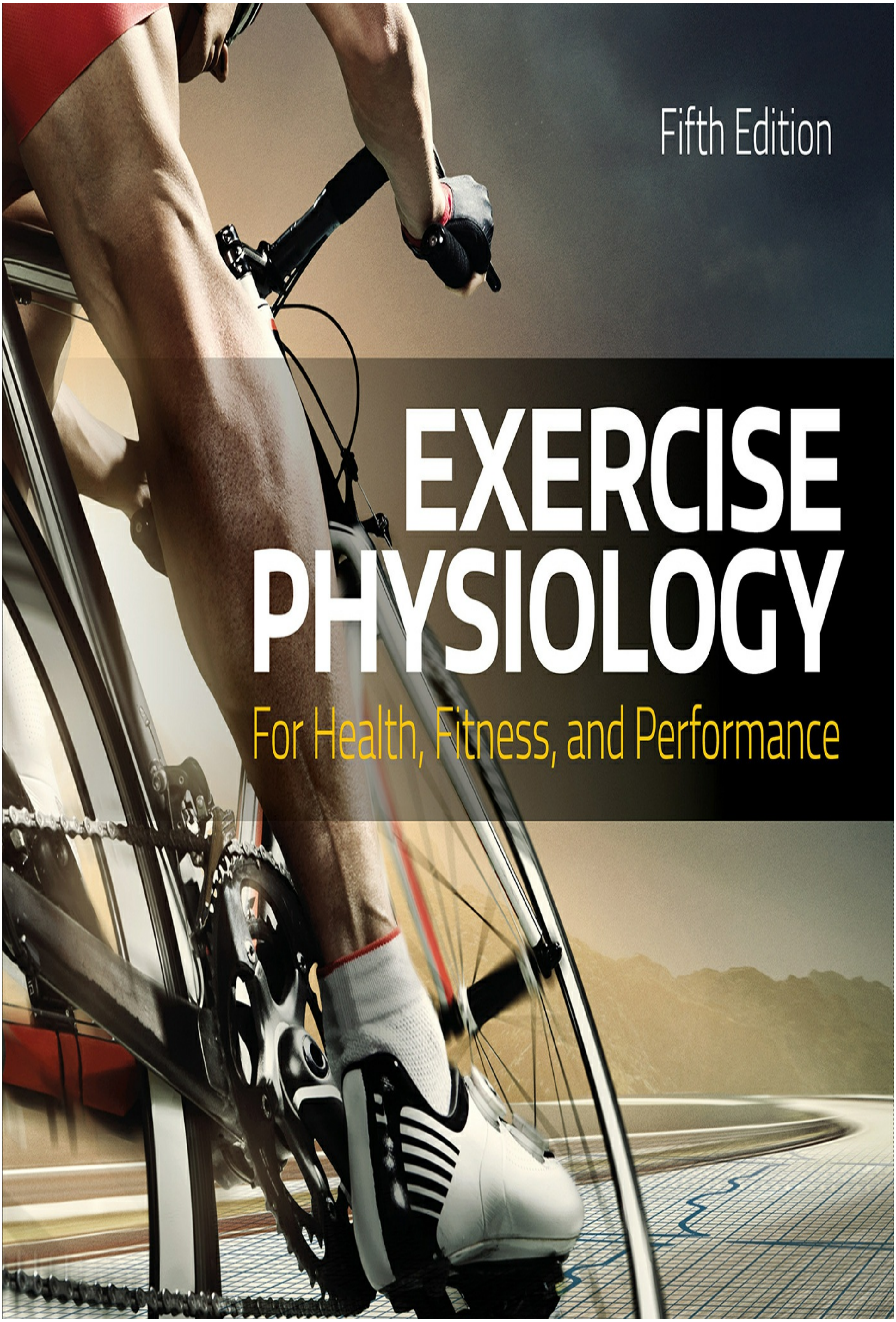

Fifth Edition

EXERCISE PHYSIOLOGY

For Health, Fitness, and Performance


Sharon A. Plowman
Denise L. Smith
Wolters Kluwer

Exercise Physiolog y

FOR HEALTH, FITNESS, AND PERFORMANCE

Fifth Edition

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Skidmore College

Wolters Kluwer

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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 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

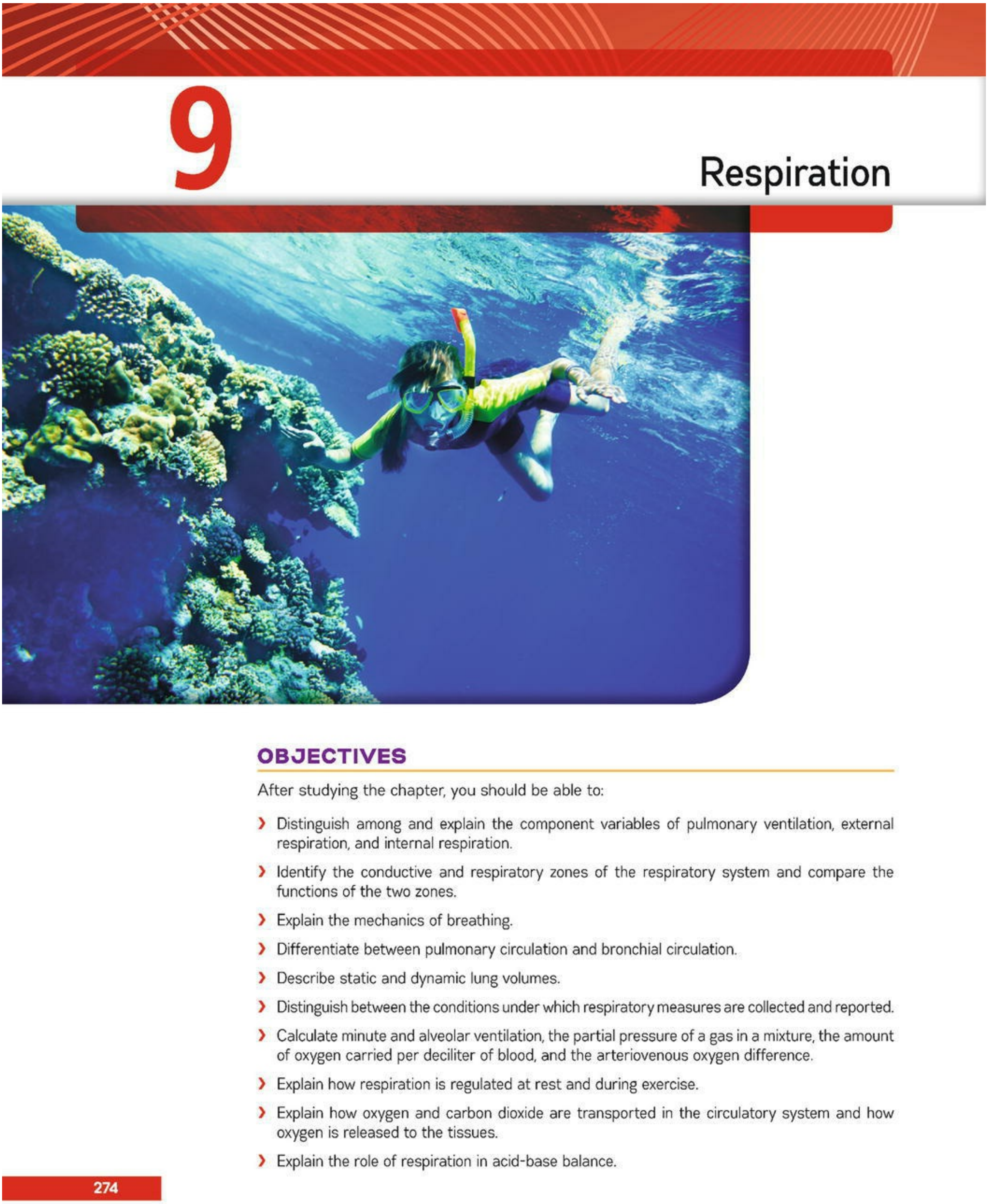
You can find this useful resource just inside the front cover of the text.

Commonly Used Symbols and Abbreviations

$(A\text{-}a)PO_2$diff	difference between partial pressure of oxygen in alveoli and arterial blood
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
AN	anorexia nervosa
ANS	autonomic nervous system
AP	action potential
ATP	adenosine triphosphate
ATP-PC	phosphagen system
ATPS	atmospheric temperature and pressure, saturated air
AV	atrioventricular
BCAA	branched chain amino acids
BED	binge eating disorder
BF	body fat
BMC	bone mineral content
BMD	bone mineral density
BMI	body mass index
BMR	basal metabolic rate
BN	bulimia nervosa
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
CO_2	carbon dioxide
CP	creatine phosphate
CR-10	category ratio scale of perceived exertion
CVD	cardiovascular disease
D_B	density of the body
D_W	density of water
DBP	diastolic blood pressure
DOMS	delayed-onset muscle soreness
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
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_A	mass of the body in the air

Chapter Objectives

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



9 Respiration

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.

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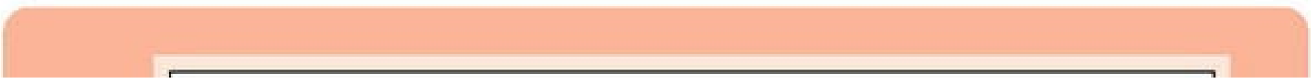
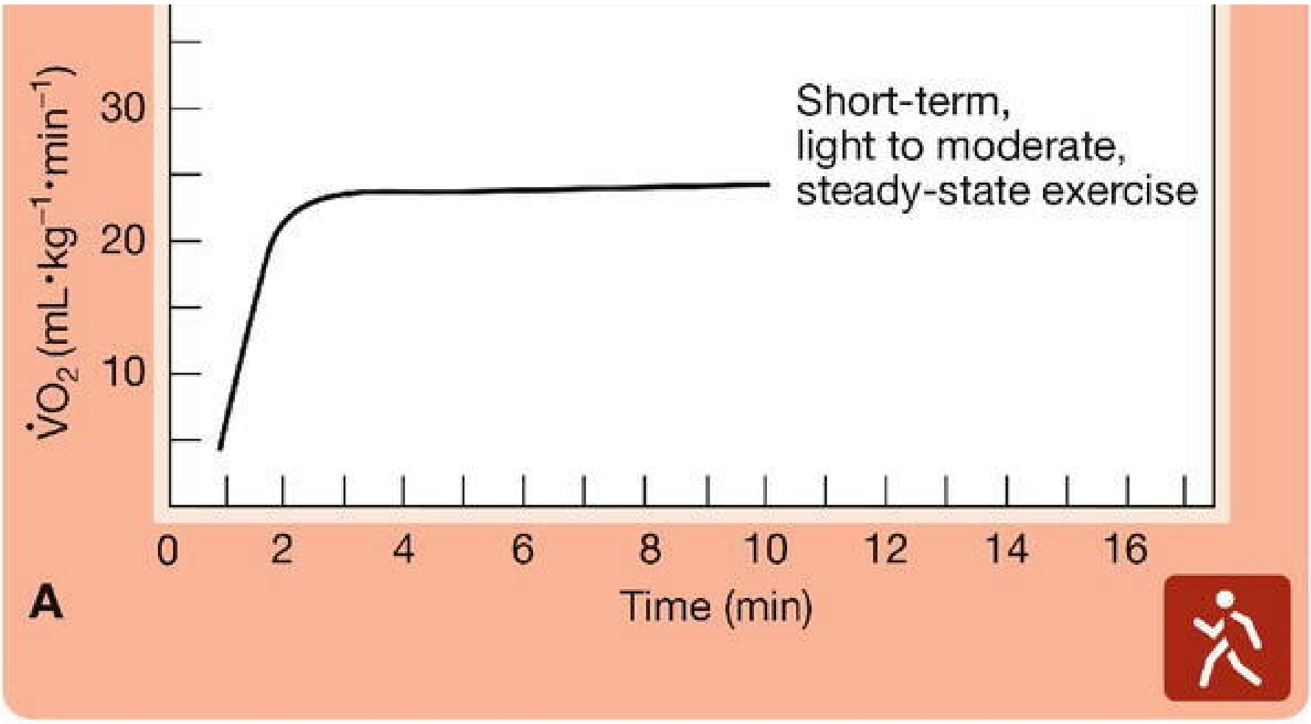
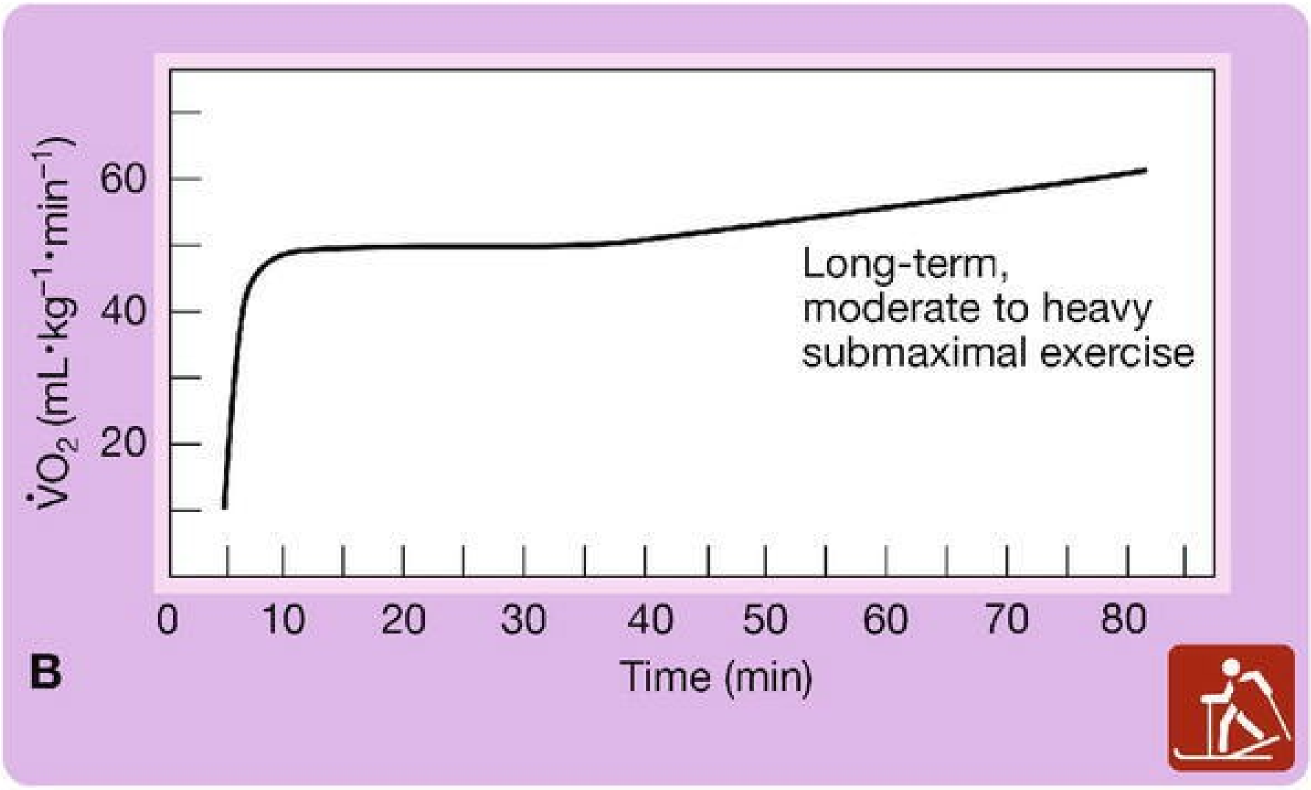
Data Graphs

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

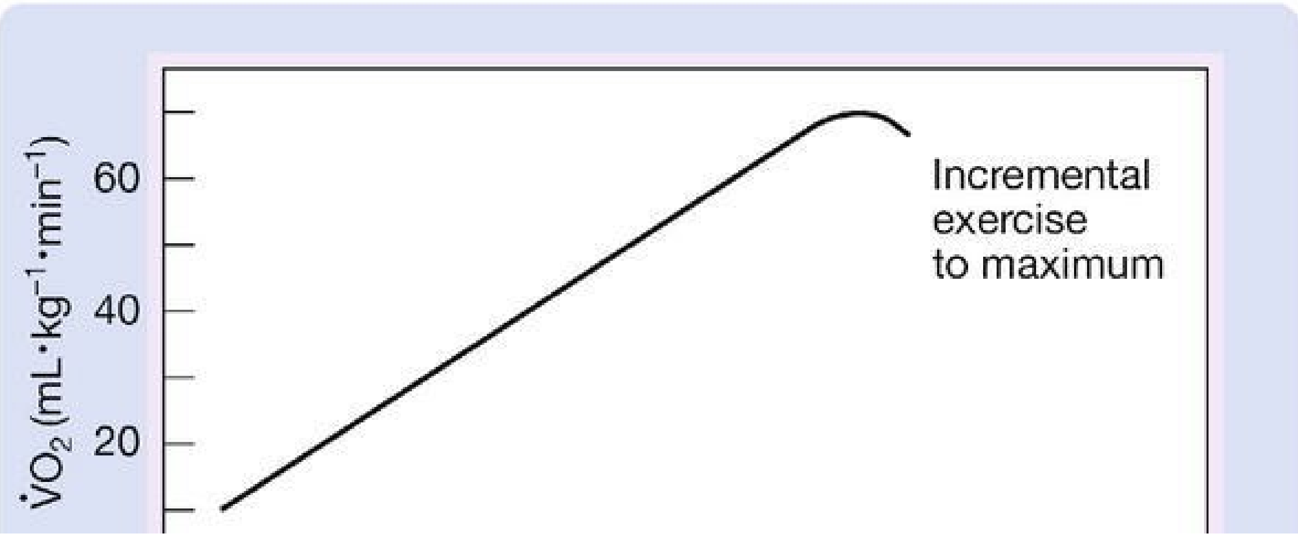



V̇O2 (mL·kg−1·min−1)
30
20
10
Short-term,
light to moderate,
steady-state exercise
0
2
4
6
8
10
12
14
16
Time (min)

A


V̇O2 (mL·kg−1·min−1)
60
40
20
Long-term,
moderate to heavy
submaximal exercise
0
10
20
30
40
50
60
70
80
Time (min)

B


V̇O2 (mL·kg−1·min−1)
60
40
20
Incremental
exercise
to maximum

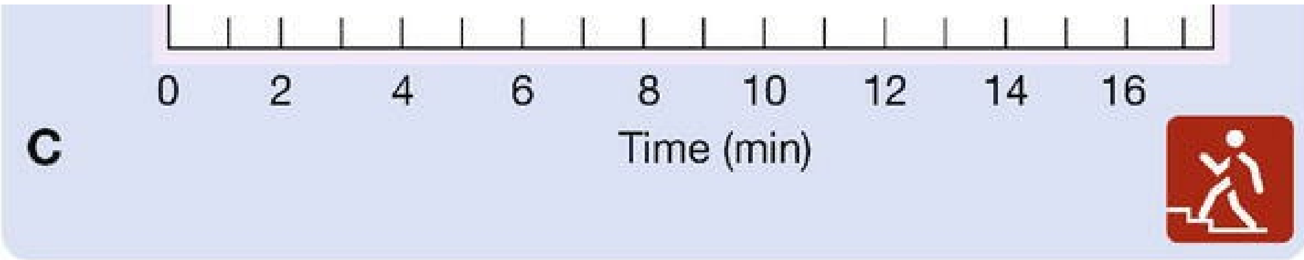


FIGURE 4.4 Oxygen Consumption Responses to Various Exercises.
A. Short-term, light to moderate, submaximal aerobic exercise. **B.** Long-term, moderate to heavy, submaximal dynamic aerobic exercise. **C.** Incremental aerobic exercise to maximum.

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		

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 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.

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 both living and training either at high altitude (2,500–2,700 m, 8,260–8,900 ft), called high-high condition, or at sea level, called low-low control condition.

Thirty-nine athletes completed 2 weeks of sea-level familiarization and 4 weeks of sea-level training before being randomized into three groups of 13 athletes (nine males and four females in each group) for 4 weeks of high- or low-altitude or sea-level training and living. Training was periodized and tapered before all tests for all groups. As expected, those training at high altitude did so at a slower speed and at a lower percentage of maximal oxygen uptake than those at sea level. However, the training intensity of the low-altitude training group was reduced by 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 difference was significantly higher for both altitude groups at velocities near 5,000-m run time trial speeds after altitude training. Velocity at $\dot{V}O_2$max increased only for the high-low group. The only group that significantly improved its 5,000-m time was the high-low group, by an average of 13.4 ± 10 seconds. This improvement persisted for at least 3 weeks after the return from altitude, at which point testing stopped.

These results suggest that an improvement in sea-level performance from 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).

simulated situations include the use of hypobaric chambers or hypoxic inhalers.

A meta-analysis (Bonetti and Hopkins, 2009) investigated the effects on performance measured at or near sea level and related physiological measures of adaptation to six different variations of altitude training. These were (1) natural live high, train high (LHTH); (2) natural live high, train low (LHTL); (3) artificial (simulated) LHTL with long (8–18 hours) continuous exposure to "altitude"; (4) artificial LHTL with brief (1.5–5 hours) continuous exposure to "altitude"; (5) brief (<1.5 hours) intermittent periods of artificial hypoxia; and (6) artificial live low, train high (LLTH). Subelite athletes were found to achieve substantial enhancement of maximal endurance power output with #2 (natural live high, train low (4.2%)), #5 (artificial brief intermittent LHTL (2.6%)), and #3 (long continuous artificial LHTL (1.4%)). Elite athletes benefited only from #2 natural LHTL (4.0%). Thus, LHTL seems best for both nonelite and elite athletes.

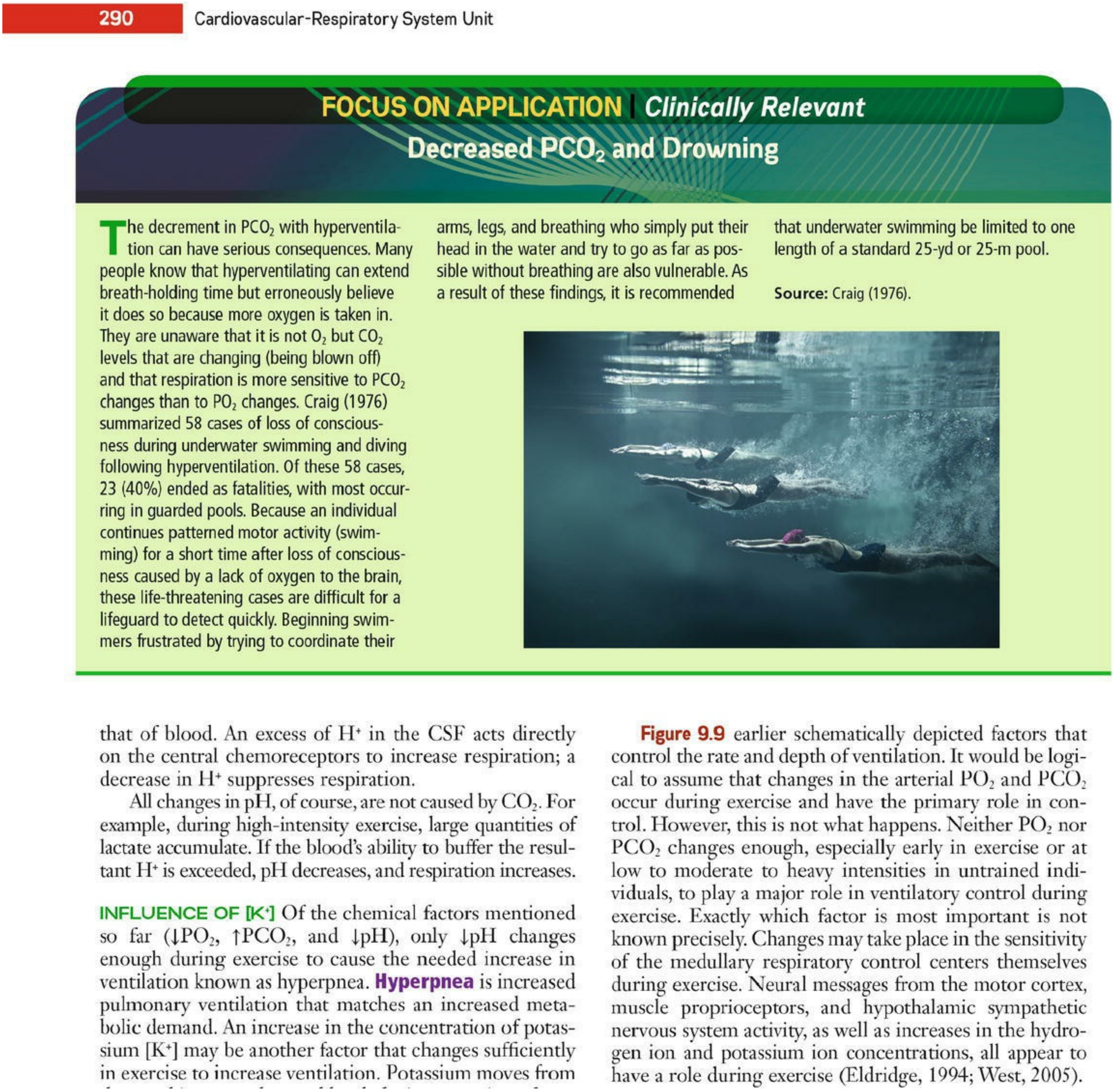
If the "live high, train low" approach is taken, the following guidelines are important (Brugniaux et al., 2006a,b; Lundby, 2012; Rusko et al., 2004; Sinex and Chapman, 2015):

1. For those with sufficient time and resources, the LHTL model with natural altitude exposure is recommended. The altitude should be at least between 2,100 and 2,500 m (~6,700–8,200 ft) but less than 3,000 m (~9,800 ft) while training should take place at ≤1,250 m (~4,100 ft or less). If circumstances require it, simulated altitude can be used.
2. Hypoxic exposure should be greater than 12 $hr \cdot d^{-1}$, and preferably 16 $hr \cdot d^{-1}$.
3. Training should last at least 3–4 weeks.
4. High-intensity training must be maintained as if altitude were not involved.

The best time to return from altitude training prior to a major competition for peak performance remains to be determined. Conventional wisdom includes several phases relative to performance expectations: (1) return days 1–7, an initial improvement; (2) days 3–14, decrements in performance and reduced training capability; (3) days 14–20+, a high plateau in performance; and (4) days 36–46, possible benefits. Even given the overlapping days, the best timing may ultimately depend upon individual responses. Athletes who exhibit a high level of ventilatory acclimatization or mechanical limitations to ventilatory flow may need a period of sea-level training before competition; athletes with a faster than normal decline in RBC mass may need to compete as soon as possible upon return from altitude. Individual variation in the 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.



290 Cardiovascular-Respiratory System Unit

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).

that of blood. An excess of H^+ in the CSF acts directly on the central chemoreceptors to increase respiration; a decrease in H^+ suppresses respiration.

All changes in pH, of course, are not caused by CO_2. For example, during high-intensity exercise, large quantities of lactate accumulate. If the blood's ability to buffer the resultant H^+ is exceeded, pH decreases, and respiration increases.

INFLUENCE OF $[K^+]$ Of the chemical factors mentioned so far ($\downarrow PO_2$, $\uparrow PCO_2$, and $\downarrow$pH), only $\downarrow$pH changes enough during exercise to cause the needed increase in ventilation known as hyperpnea. **Hyperpnea** is increased pulmonary ventilation that matches an increased metabolic demand. An increase in the concentration of potassium $[K^+]$ may be another factor that changes sufficiently in exercise to increase ventilation. Potassium moves from

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).

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.

mitochondria for the production of ATP. Thus, any of the following systems may limit $\dot{V}O_2max$:

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 $\dot{V}O_2max$ 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 $\dot{V}O_2max$. Medications (such as beta-blockers) that limit cardiac output also cause a decrease in $\dot{V}O_2max$, 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 $\dot{V}O_2max$.

Although factors in each of these systems may limit $\dot{V}O_2max$, the question remains: What limits $\dot{V}O_2max$ 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 $\dot{V}O_2max$ (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.

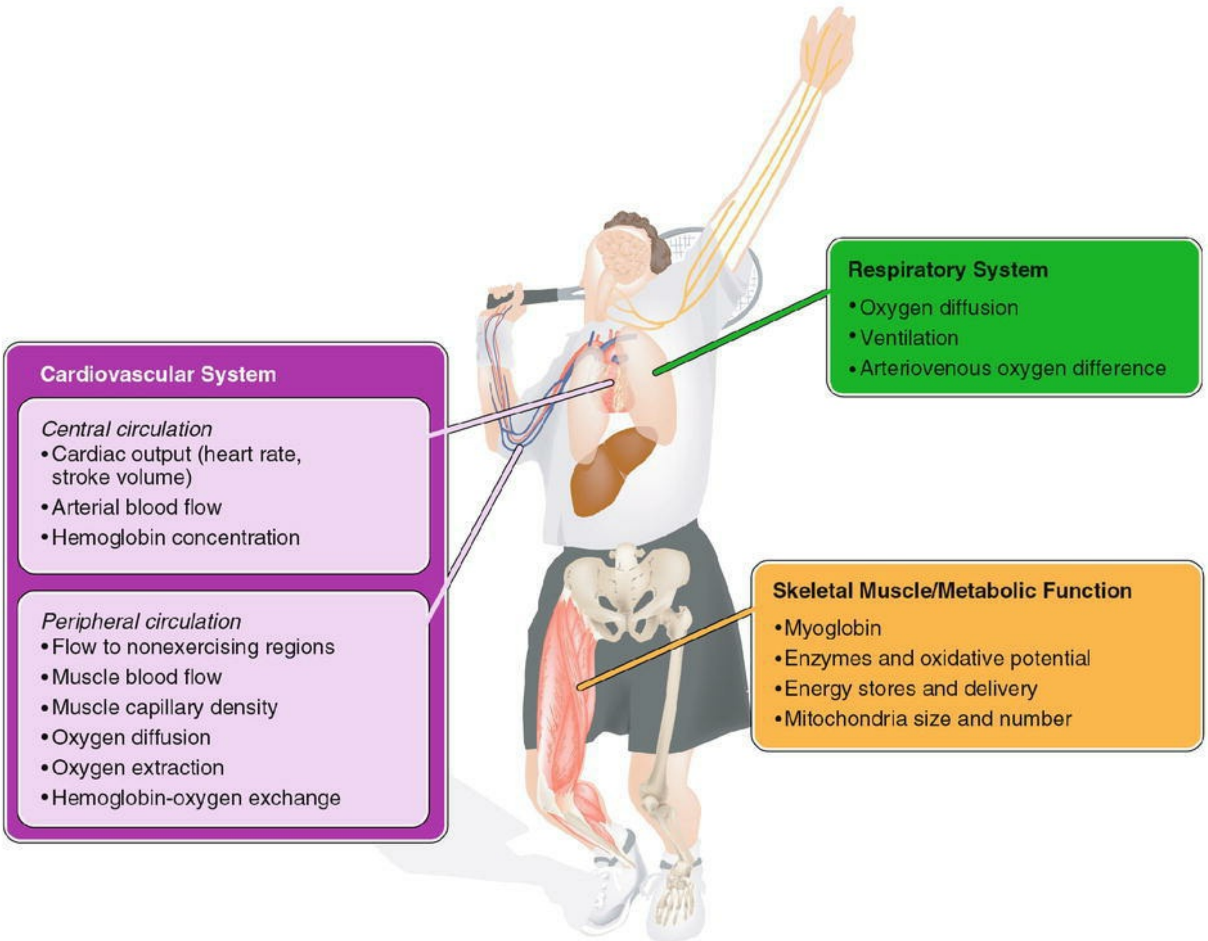


FIGURE 12.10 Possible Limitations to Maximal Oxygen Consumption.
Source: Modified from Rowell (1993).

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.

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

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

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 calculated in 1 and 2, use Equation 7.1 to calculate D_B and Equation 7.2 to calculate %BF.
4. Phyllis would like to be 19% BF. Use Equations 7.4, 7.5, and 7.6 to determine whether she needs to gain or lose weight to achieve this goal, and if so, how much.

Check your answer in Appendix C.

Now read the Check Your Comprehension box and answer the problems given. The data are presented as they would be recorded during an actual experiment. You will need to do some conversions and analysis to select the correct M_A and M_W. As you do each calculation, mentally review the reasons for each step to ensure that you understand the underlying principles.

When the measuring technique is properly conducted, the error of %BF determined by densitometry is approximately ±2.7% for adults. This error range is primarily due to variations in the composition of the FFM (Lohman, 1981). The error is always lowest when the individual being tested closely matches the sample on which the equation was developed (Heyward and Stolarczyk, 1996).

Densitometry: Children and Adolescents and the Older Adult

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

Clear and Accurate Artwork

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

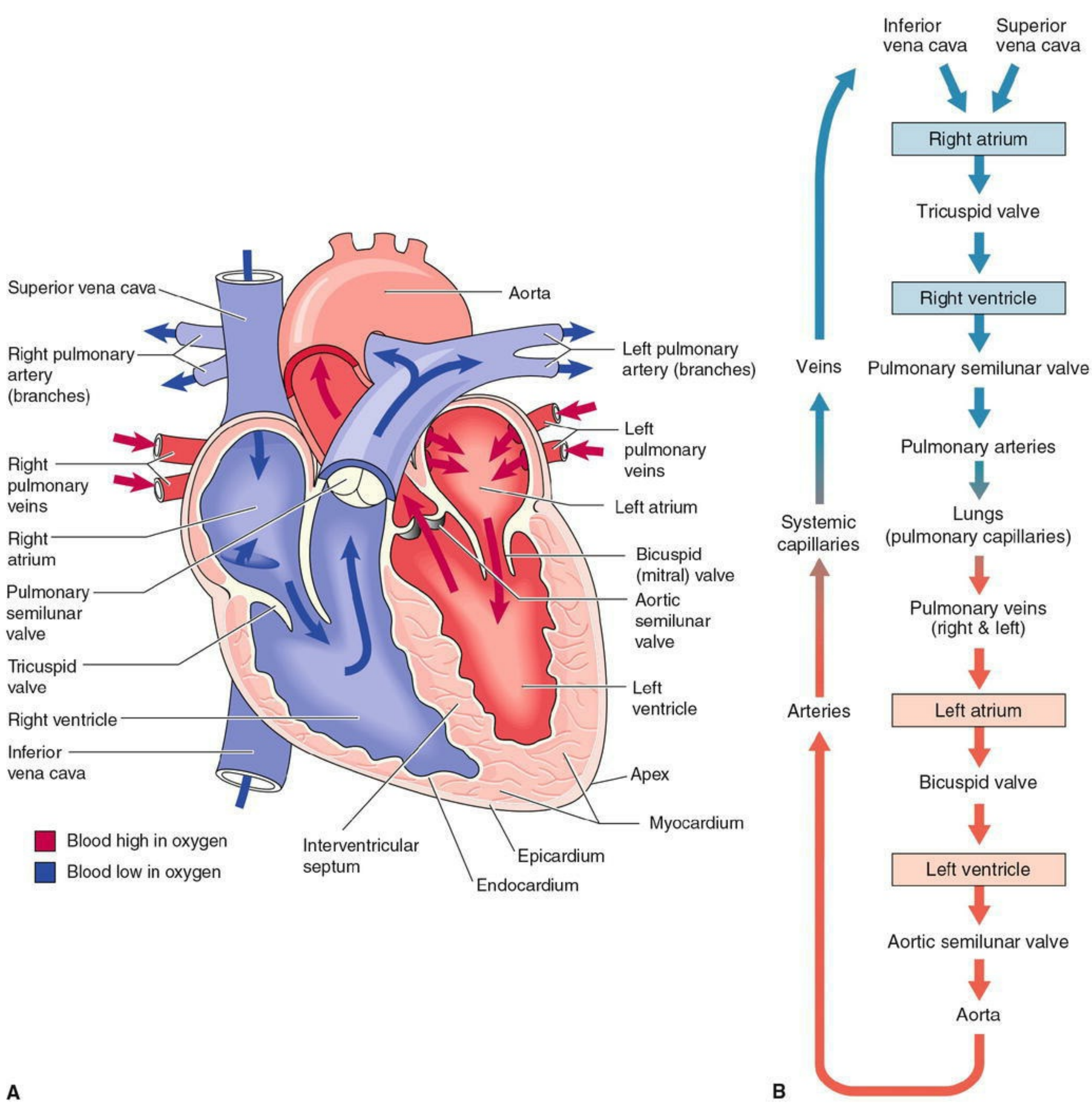


FIGURE 11.2 Blood Flow through the Heart.
A. Schematic of the heart. **B.** Summary of blood flow through the heart.

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.

striction), placing them at greater risk for hypothermia. Evidence suggests that older adults often have a blunted sensitivity to cold, such that they may be slower to make appropriate behavioral changes in a cold environment (ACSM, 2006).

SUMMARY

1. Environmental conditions that affect human thermoregulation are ambient temperature (T_{amb}), relative humidity, and wind speed. The heat index assesses the risk of thermal injury from measures of ambient temperature and relative humidity. The windchill index assesses the risk of cold-induced injury from wind speed and ambient temperature.
2. Body temperature results from a balance of heat gain and heat loss. Most heat gain results from the body's metabolic heat production. Heat can be lost from the body through radiation, conduction, convection, and evaporation.

REVIEW QUESTIONS

1. Diagram the thermal balance that is typically maintained at rest. Indicate how this balance is altered during exercise in hot and cold environments.
2. Identify the factors that influence heat exchange, and discuss how each facilitates or impedes the transfer of heat to and from the body.
3. Describe the cardiovascular responses to incremental exercise in a hot environment compared to a thermoneutral environment, and explain why these occur.
4. What is the importance of acclimatization? How much time is needed for acclimatization to occur?
5. Explain the influence of hydration level on an individual's response to exercise in the heat. What is necessary to maintain adequate hydration?
6. Discuss the effects of fitness level and body composition on an individual's response to exercise in the heat.

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.

1. The force of contraction is generated by the process that slides the actin filament over the myosin filament.
2. The lengths of the thick and the thin filaments do not change during muscle contraction.
3. The length of the sarcomere decreases as the actin filaments slide over the myosin filaments and pull the Z disks toward the center of the sarcomere.

See animation, Sliding Filament Theory at http://thePoint.lww.com/Plowman5e.

ens as the result of the attachment of the myosin heads with the active site on actin and the subsequent release of stored energy that swivels the myosin cross-bridges. This step causes the actin to pull the Z disk toward the center of the sarcomere, which in turn causes the sarcomere, and thus the muscle fiber, to shorten. The ability of the sarcomere to deform elastically during contraction is due primarily to the structural cytoskeleton proteins whose modular architecture and flexibility permit change in length (Tskhovrebova and Trinick, 2012).

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.

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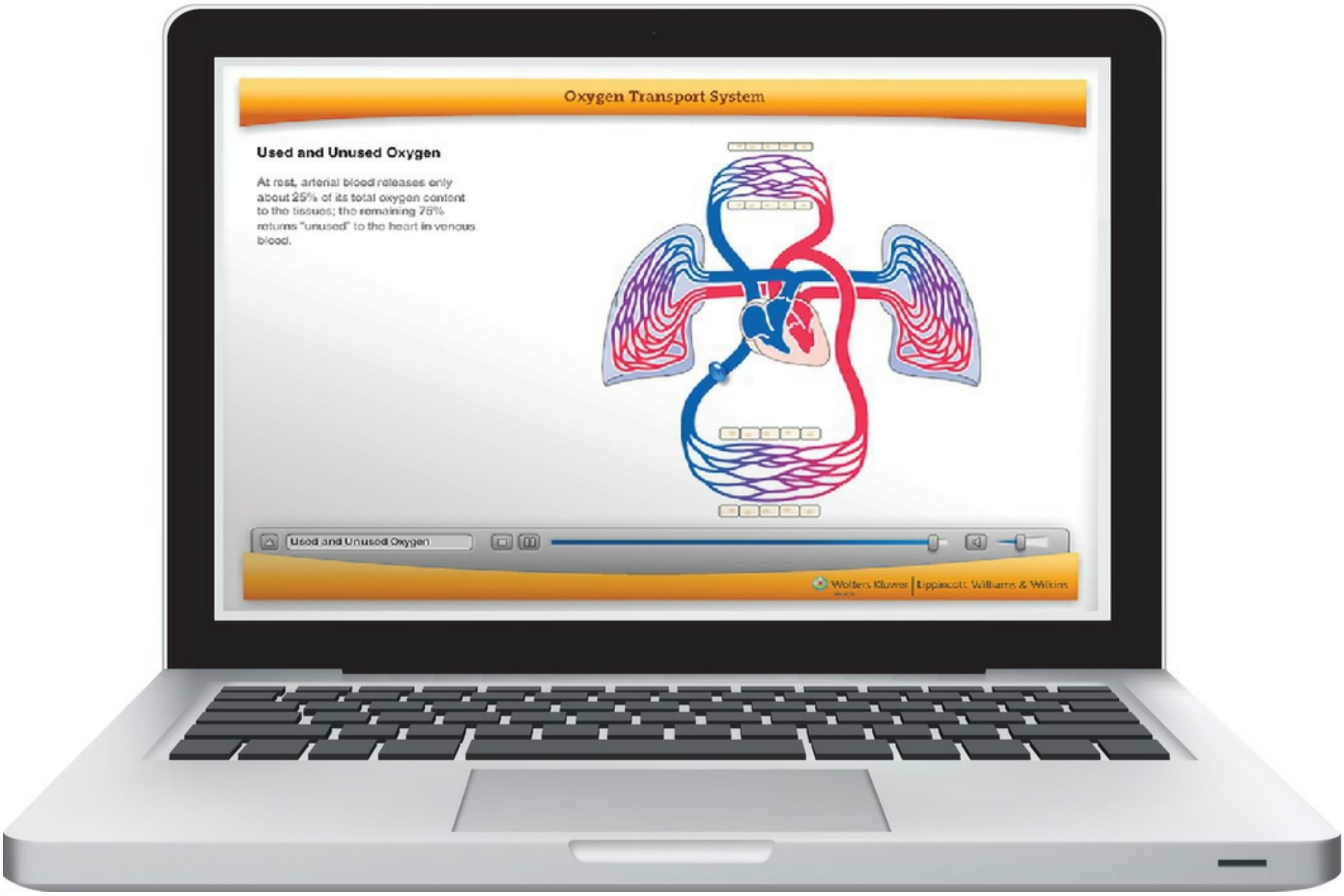
Additional Learning and Teaching Resource s

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

http://thePoint.lww.com/Plowman



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
- Quiz Bank Questions
  - Multiple Choice
- Worksheets
  - True/false (with space for corrections)
  - Tables to fill in
  - Matching
  - Calculations
- 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

Commonly Used Symbols and Abbreviations

$(A\text{-}a)PO_2$ diff difference between partial pressure of oxygen in alveoli and arterial blood

$a\text{-}vO_2$ diff 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

AN anorexia nervosa

ANS autonomic nervous system

AP action potential

ATP adenosine triphosphate

ATP-PC phosphagen system

ATPS atmospheric temperature and pressure, saturated air

AV atrioventricular

BCAA branched chain amino acids

BED binge eating disorder

BF body fat

BMC bone mineral content

BMD bone mineral density

BMI body mass index

BMR basal metabolic rate

BN bulimia nervosa

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

CO_2 carbon dioxide

CP creatine phosphate

CR-10 category ratio scale of perceived exertion

CVD cardiovascular disease

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
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 cholesterol
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 cholesterol
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
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

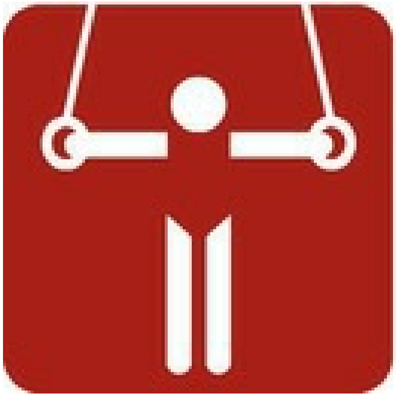
Icon Identification Guide

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

Contents

NEUROENDOCRINE-IMMUNE SYSTEM UNIT

1 The Warm-Up

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."
- 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 "mixed gender" time (meaning achieved in a race in which men also competed) was set in 2003 at 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.

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.

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:

FIGURE 1.1 Warming up in Preparation for Performance.

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.

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 three. This concept is represented by the circle and cross arrows in Figure 1.2 .

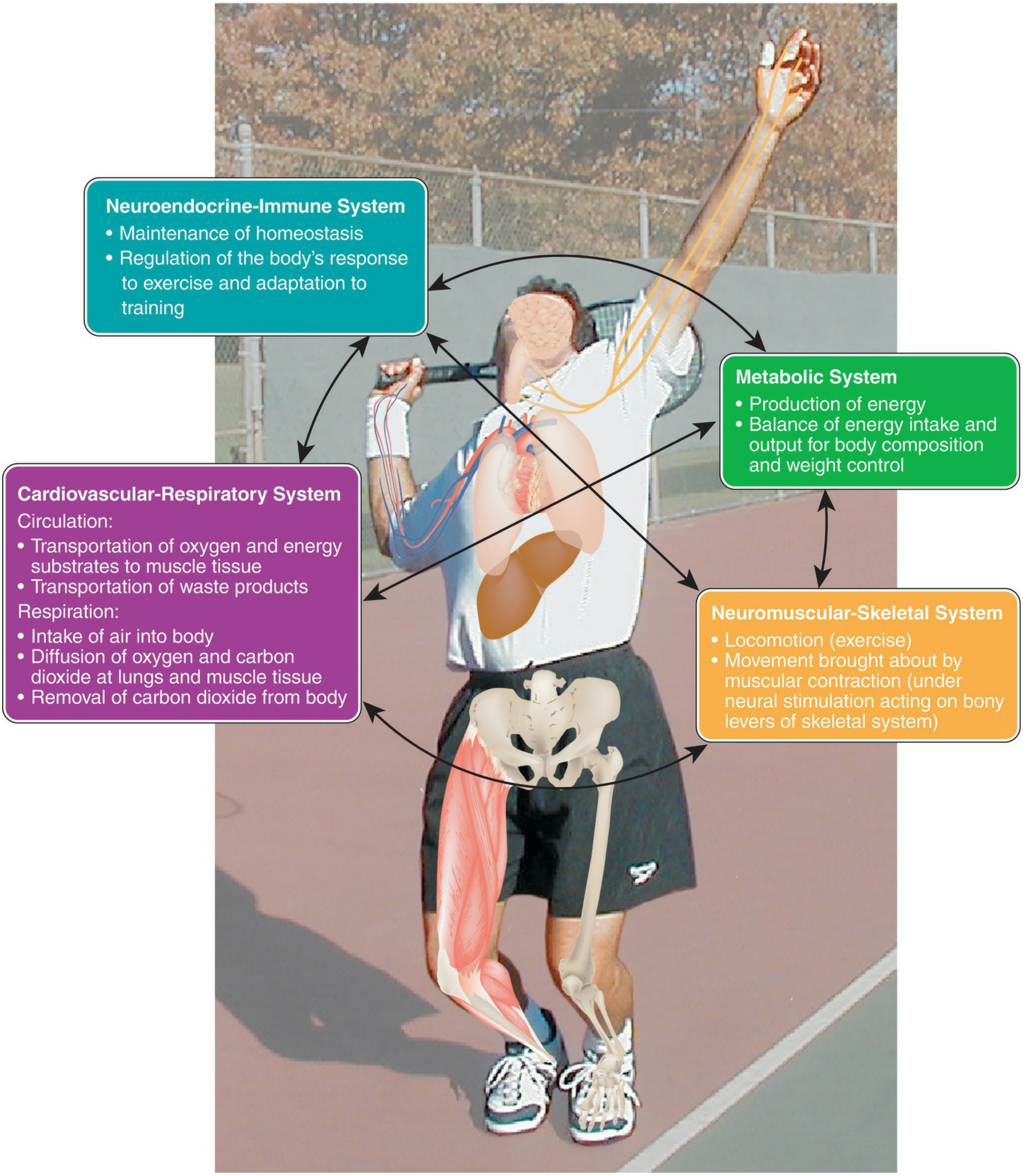


FIGURE 1.2 Schematic Representation of Text Organization.

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 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: